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SUBMARINE HIGH PRESSURE DEHYDRATOR PERFORMANCE TEST

NAVSSES PROJECT NUMBER B-5960

FINAL REPORT
JUNE 1988

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY 2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	3 DISTRIBUTION / AVAILABILITY OF REPORT Distribution unlimited; requests for this document must be referred to Defense
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION NAVAL SHIP SYSTEMS ENGINEERING STATION 6b. OFFICE SYMBOL (If applicable) 024B	7a NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) US NAVAL BASE PHILADELPHIA, PA 19112-5083	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING / SPONSORING ORGANIZATION NAVAL SEA SYSTEMS COMMAND 8b OFFICE SYMBOL (If applicable) PMS-390	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) WASHINGTON, DC 20362	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. N0002486, N0002486 PROJECT NO. PO 01563, PO 01564 TASK NO WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
FINAL REPORT - SUBMARINE HIGH PRESSURE DEHYDRATOR PERFORMANCE TEST (U)

12. PERSONAL AUTHOR(S)
Colahan, Denis   Newell, Scott   Garhart, Adria

13a. TYPE OF REPORT	13b TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Test & Evaluation	FROM 4/87 TO 1/88	1988 June 07	94

16. SUPPLEMENTARY NOTATION

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	High Pressure Dehydrators; Desiccant; High Pressure Air Compressor; Dry Air; Dewpoint/Frostpoint Monitors
13	10	.1	

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

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Evaluation of the test data indicates that the dehydrators and filters presently in use meet or exceed current specifications. Definite trends exist which might be adapted to use as predictors. While the equipment under test performed satisfactorily, there were definite indications that the widely accepted Navy standard moisture/dewpoint measuring equipment is deficient, at least in the ranges of interest.

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a NAME OF RESPONSIBLE INDIVIDUAL Denis Colahan	22b TELEPHONE (Include Area Code) (215) 897-7244 — 22c OFFICE SYMBOL 024B

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

3. Technical Information Center, Defense Logistics Agency, Cameron Station, Alexandria, Virginia 22304-6145.

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ABSTRACT

The Naval Ship Systems Engineering Station has conducted performance testing on high pressure air system equipment found on SSN 637 and 688 class submarines. The tests compared the equipment's filtering and air dehydration performance under standard and non-standard operating conditions. The results of testing include dewpoint versus time, dewpoint versus regeneration temperature and oil removal versus time data.

Evaluation of the test data indicates that the dehydrators and filters presently in use meet or exceed current specifications. Definite trends exist which might be adapted to use as predictors. While the equipment under test performed satisfactorily, there were definite indications that the widely accepted Navy standard moisture/dewpoint measuring equipment is deficient, at least in the ranges of interest.

SUMMARY

NAVSSES Philadelphia conducted a series of in-house tests on SSN 637 and 688 class high pressure air system equipment from 08 April 1987 through 04 January 1988. These tests were undertaken to quantify the performance of filters and dehydrators operating under standard as well as non-standard conditions. Results demonstrated repeatable trending of outlet moisture levels from the dehydrator over time. During breakthrough, dehydrator outlet moisture levels were shown to increase in a steady fashion over an 8 to 10 hour time period. Data from desiccant regenerations with 400°F, 300°F, 200°F, 100°F and ambient temperature purge air demonstrated a direct relation between dehydrator drying ability and regeneration temperature. Tests conducted on air stream oil filtering performance show no significant reduction in capability after 650 hours in service.

Recommendations are presented which include further testing to quantify the effects of decreased frequency of moisture blowdowns, decreased dehydrator purge flow rates and increased air flow rates through the system. It is also recommended that state-of-the-art instrumentation for moisture monitoring and calibration be tested.

EXECUTIVE RESULT SUMMARY

DEWPOINT INDICATORS

*Air Dry chilled mirror unit was erratic
*General Eastern electronic chilled mirror unit showed more stability than the Air Dry unit but did not function well in very low moisture ranges
*Kahn, Panametrics, DuPont and MCM units had similar tracking and showed respectable repeatability and response times
*Pneumetrics thick-filmed sensor showed slower response times

BREAKTHROUGH

*Did not occur instantaneously but over a repeatable 8 to 10 hour period
*Occurred 40 to 50 hours after normal regeneration
*Showed potential for formula governing dehydrator performance
*Established occurrance of steady-state dewpoint after normal regenerations

OIL CONTAMINATION

*Appeared to be a reasonably steady process
*Filter did not suffer breakdown at any point in testing
*Breakthrough hours tended to decrease with time as oil accumulated in the desiccant
*Steady-state dewpoints tended to increase with time as oil accumulated in the desiccant
*Similar patterns of oil concentration found in desiccant towers

REACTIVATION TEMPERATURES

*400°F - averaged 52 hours until breakthrough - average dewpoint after regeneration was -80°F
*300°F - averaged 49 hours until breakthrough - average dewpoint after regeneration was -65°F
*200°F - averaged 33 hours until breakthrough - average dewpoint after regeneration was -45°F
*100°F - averaged 10 hours until breakthrough - average dewpoint after regeneration was +25°F
*Ambient temperature - showed virtually no air quality improvement - average dewpoint drop after regeneration was 10°F
*Decreasing pattern of hours until breakthrough with lower temperatures
*Decreased regeneration quality at lower temperatures as shown by dewpoints after regeneration

DEHYDRATOR PERFORMANCE

*Produced good quality dry air far longer than designed 4 hour operating cycle
*Output air well within limits of acceptable air
*Significant maintenance required during testing

1.0 INTRODUCTION

High pressure compressed air on Navy submarines serves a variety of subsystems vital to the boat's operation and mission. Among the systems served are: steering and hydraulics, emergency blow, deballasting, oxygen generation, reactors and weapons. For reliable and efficient operation of these systems the compressed air must be both clean and dry. The standards for air purity are set forth in Chapter 9490 change 10 of NAVSEA 0901-LP-490-0003 "Compressed Air Plant Systems" and call for a moisture level no greater than 15 PPM by weight (PPMw). This is equivalent to a $-65^{o}F$ dewpoint at atmospheric pressure ($+15^{o}F$ dewpoint at 4500 psig).

High pressure compressed air on 688 and 637 Class Submarines is produced by oil lubricated compressors at pressures up to 4500 psig. The compressed air is saturated with moisture and includes entrained lubrication oil when discharged from the compressor. The air is passed through a separator flask, a CUNO filter and a desiccant air dryer before distribution throughout the boat. Efficient removal of entrained moisture and oil by the separator and CUNO filter reduces the loading and potential contamination of the dryer's desiccant. This extends the useful life of the desiccant and promotes clean dry air for storage and use. Compressed air which does not meet the 15 PPMw moisture criteria may promote condensation and subsequent corrosion in storage flasks. High moisture levels could also contribute to the occurrance of reducing valve freeze-up and malfunction.

In order to quantify high pressure dehydrator and filter performance, NAVSSES constructed a test stand utilizing submarine compressors, separators, filters, dryers and associated valves and piping. Designated the SMMSO/NAVSSES HIGH PRESSURE AIR DEHYDRATOR TEST STAND, it is located in an environmentally controlled 10' x 30' test cell in NAVSSES Building 77H. The objective of this initial series of tests was to monitor the performance of the dehydrator and filters under standard and non-standard operating conditions. Dehydrator outlet moisture levels and oil analysis of various components were the primary parameters analyzed.

2.0 TEST AUTHORIZATION

Testing of the High Pressure Air Dehydrator System typically used on the 637 and 688 Class submarines was authorized by NAVSEA PMS-390 Document Numbers N0002486P001563 dated 28 July 1986 and N0002486P001564 dated 28 July 1986.

3.0 OBJECTIVES

Testing was conducted with three main objectives:

a)Determine if dewpoint monitoring over time establishes a formula for predicting dehydrator performance.

b)Determine the sensitivity and note the degradation of the dehydrator drying capacity as a function of oil adsorption by the desiccant.

c)Determine the effects of reduced reactivation temperatures on dehydrator performance.

4.0 SYSTEM DESCRIPTION

The High Pressure Air Dehydrator Test Stand located in NAVSSES Building 77H is shown in Figures C-1 and C-2 of Appendix C. The high pressure air compressor is Worthington Class AA, serial number L68938, rated at 13 CFH, 4500 psig (See Figure C-3). The compressor is a four stage reciprocating design with the first and third stage on one crank throw and the second and fourth stage on the opposite crank throw. Cylinder lubrication is provided by a Menzal lubricator which replaced the original Nathan high speed lubricator and provides improved control of cylinder lubrication. This compressor was obtained from the deactivated submarine USS ROBERT E. LEE (SSBN-601).

Air discharged from the compressor is passed through the moisture separator shown in Figure C-4. The separator removes entrained moisture and contaminents by rapid reversal of the direction of air flow. Collected moisture must be manually removed via the blowdown line.

The CUNO filter immediately downstream of the moisture separator is designated CUNO I. Manufactured by the AMF CUNO division, model 1H1 and utilizing AMF filter element U78B2, its filtration is rated at 5 microns nominal, 8 microns absolute. This unit coalesces oil aerosols and traps foreign matter carried over by the separator. CUNO I is also manually blown down. Figure C-5 is a sectional view of this filter.

At the discharge of CUNO I, compressed air may be directed via one of two paths. The first path contains a second CUNO filter which is designated CUNO II. Attached to the blowdown outlet of CUNO II is a third filter housing designated CUNO III. As shown in Figure C-6, CUNO II contains a modified filtering arrangement designed to capture contaminents down to 0.3 microns. Excess oil collected would be drained to CUNO III for capture and analysis. The alternate flow path would bypass CUNO II and III and deliver air through a flowmeter to the inlet of the high pressure dehydrator. Actual submarine HP air systems employ the separator and CUNO I, but do not have CUNO II and III or a flowmeter in-line. The purpose of CUNO II and III was to quantify the amount of oil which was not captured by the first CUNO filter.

The high pressure flow meter is manufactured by Taylor Instruments and carries serial number 3407TDT0021-01. The meter is an orifice type flow meter with an accuracy of +/- 1/2% of flow, and a range of 0 to 3613 SCFH. (See Figure C-7)

The dehydrator is an Air Dry Corp model 10101-7, rated at 150 SCFM, and 4500 psig and is shown in Figures C-8 and C-9. This unit has two primary desiccant towers, allowing simultaneous drying of the air stream in one while regenerating the second. There is also a bypass tower which contains a replaceable desiccant cartridge used for emergency or casualty conditions. The air to be dried enters the dehydrator through a prefilter. From there it enters the upper manifold and is directed to one of

the two desiccant towers to be dried. The towers were filled with 1/8" diameter Alcoa H-152 activated alumina desiccant, NSN 9G-6850-00-738-1672. Upon leaving the tower the dried air passes through a screen filter and lower manifold check valves before entering the P-1200 manifold. In the P-1200 manifold a back pressure valve set to open at 3400 psig permits the air to flow into the boat's air system and to the dehydrator purge system if required.

The purge air system is used in conjunction with the reactivation of desiccant in the off-line tower. On 688 Class submarines purge air may be taken from either of two sources; external compressed air supplied from the low pressure air system or pressure reduced HP air bled from the dehydrator outlet stream. During reactivation, purge air is admitted to a heater via a solenoid valve. The heated air is then passed through a lower manifold check valve and routed to the tower undergoing reactivation. The purge air passes through the tower, warming the desiccant and carrying away adsorbed moisture. The purge air is routed to the upper manifold and released through an orifice plate and silencer to the atmosphere. Periodically, service changeovers are performed which allow the two towers to exchange drying and reactivation modes.

Appendix C presents further details on the test equipment and dewpoint monitoring instrumentation.

Air discharged from the dehydrator was monitored for moisture content with a number of dewpoint indicators. The indicators measured moisture through one of the following four means: chilled mirror, aluminum oxide sensor, piezoelectric crystal or silicon chip sensor. During the course of testing, a total of eight different units were tested and compared. Appendix D contains a matrix describing the various indicators and comparing salient features.

5.0 TEST PROCEDURE

Testing was broken down into five Phases numbered I through V. During all testing the standard Navy schedule for blowing down moisture from the compressor, separator, CUNO filter and dehydrator prefilter was adhered to. The compressor's automatic drain system was verified on an hourly basis to be draining at eight minute intervals. The moisture separator and CUNO filter (CUNO I) were manually drained every 30 minutes and the dehydrator prefilter was manually blown down every two hours.

Throughout testing, the dehydrator processed compressed air from a single compressor, and utilized high pressure dehydrated air reduced in pressure by the P-1200 manifold as the source of purge air. Compressor discharge pressure was maintained at 4000 psig while cylinder lubrication rate was maintained between 10 and 15 drops per minute during the course of testing. All operating data was logged at 15 minute intervals on data sheets shown in Appendix E. Elements used in the CUNO filters were identified alphabetically so that the designation 'CUNO IA' refers to the first filter element installed in the CUNO I housing.

At the start of testing, the dehydrator was operated until the dewpoint at system pressure was -20^{o}F as read on the Pneumetrics dewpoint indicator. Due to differences in speed of response to changes in moisture levels between this Pneumetrics unit and the DuPont, Kahn, Panametrics 1000 and Panametrics 250 units, a -20^{o}F dewpoint read on the Pneumetrics unit corresponded to a +35^{o}F dewpoint at system pressure as read by the other four. This difference in response speed is illustrated by Graphs C through F in Appendix A. To maintain consistancy across the different Phases of the test, the dehydrator was operated until a dewpoint reading of +35^{o}F at system pressure was reached, as read on the DuPont, Kahn, Panametrics 1000 and Panametrics 250 units. The chart presented in Appendix D, "Water Content of Saturated Air (LDS Curves)" shows that the upper limit on moisture content for compressed air, 15 PPMw can be translated to a dewpoint of +20^{o}F at system pressure. Securing testing at a dewpoint of +35^{o}F at system pressure insured a complete desiccant breakthrough and allowed standardization of testing between Phases.

Phase I testing was conducted for 156 hours to establish baseline data related to steady state dehydrator outlet dewpoints and typical tower breakthrough times. The compressor and dehydrator were operated approximately 8 hours per day, 5 days per week. Data was also taken to quantify the amount of oil which was not captured by CUNO I. The air path during Phase I was through the separator, CUNO I and CUNO II to the dehydrator. CUNO III was on line to collect any contaminents draining from CUNO II. Prior to the start of testing, the dehydrator desiccant was freshly replaced and each tower cycled through a 400^{o}F regeneration. During Phase I, all regenerations were conducted at 400^{o}F. Phase I testing was terminated upon breakthrough of the

dehydrator's left tower after 85 hours of operation. CUNO filter IA was left intact in preparation for Phase II testing. CUNO IIA was removed and analyzed, and the filter housings for CUNO II and III were flushed with Freon to remove any oil accumulation. The dehydrator prefilter and desiccant were removed and forwarded, along with the CUNO IIA filter element and the CUNO II and III housing flushes, to the NAVSSES Chemistry Lab for oil analysis. See Appendix G for the procedure employed during the oil extractions.

Phase II testing was conducted for a total of 78 hours to verify the repeatability of the desiccant breakthrough times and compare the amount of oil which would not be captured by CUNO IA with amounts recorded in Phase I. (This filter comparison could indicate trends in filtering ability of new and used filter elements.) The dehydrator desiccant was replaced and each tower reactivated at 400°F prior to starting Phase II. In Phase II, the system was operated 8 hours per day, 5 days per week. The compressed air path was through the separator, CUNO IA, CUNO IIB to the dehydrator. CUNO III was not used since the expected large accumulations of oil did not materialize in Phase I. At the end of Phase II, CUNO filter IIB was removed and the CUNO II housing was flushed with Freon to remove any oil accumulation. Both CUNO IIB and the flush liquid were forwarded to the lab for analysis. CUNO IA remained in the system in anticipation of Phase III testing.

Phase III testing was conducted for 146 hours to continue with filter loading on CUNO IA and observe the amounts of oil bypassing CUNO IA over time. Test data was recorded for breakthrough times using the same desiccant as employed in Phase II. In Phase III, all reactivations were performed at 400°F. At the conclusion of Phase III, CUNO filters IA and IIC, the Freon flushes of CUNO housings I and II and the dehydrator's desiccant and prefilter were removed and forwarded to the Chemistry lab for oil analysis.

Phase IV testing was undertaken to generate data on the dehydrator's capabilities during 645 hours of continuous operation (24 hours per day, 7 days per week). Also, data from Phase IV was used to compare amounts of oil not captured by CUNO IB with those not captured by CUNO IA, and to observe the effects of oil accumulation in the desiccant on dehydrator performance. The dehydrator desiccant was replaced and each tower reactivated at 400°F prior to the start of Phase IV testing. The air path in Phase IV was through the separator and CUNO I into the dehydrator. CUNO II was bypassed in Phase IV so oil not captured by CUNO IB would go directly into the dehydrator. The breakthrough times were recorded after each moisture breakthrough, and all reactivations were performed at 400°F. At the conclusion of Phase IV, CUNO filter IB, the Freon flush of the CUNO I housing, and the dehydrator's prefilter and desiccant were removed and forwarded to the Chemistry lab for oil analysis.

Phase V testing was conducted for 642 hours to determine effects of reduced reactivation temperatures on the dehydrator's capabilities. Data from Phase V was also used to compare amounts

of oil not captured by CUNO IC with those not captured by CUNO IA and IB filters. The dehydrator desiccant was replaced and each tower reactivated at 400°F prior to the start of Phase V testing. The air path in Phase V was through the separator and CUNO I into the dehydrator; CUNO II was again bypassed. Two moisture breakthroughs occurred after normal 400°F reactivations. Then the reactivation temperature was gradually lowered in 100°F increments down to ambient temperature and two to three moisture breakthroughs occurred after each reactivation temperature. The corresponding breakthrough times were recorded for each moisture breakthrough. One final reactivation at 400°F was performed and the breakthrough time was recorded. At the conclusion of Phase V, CUNO filter IC, the Freon flush of the CUNO I housing, and the dehydrator's prefilter and desiccant were removed and forwarded to the Chemistry lab for oil analysis.

Tables 9 through 13 in Appendix H show detailed hours of operation logs for each of the five testing phases.

This completed the testing.

6.0 RESULTS

6.1 DEWPOINT INDICATORS

6.1.1 The current Air Dry Corp chilled mirror dewpoint indicator widely used as the Navy standard has (again) proven to be unreliable in the moisture range of Navy acceptable dry air (0 - 15 PPMw). Graph A in Appendix A shows the unit's erratic behavior and lack of repeatability. This graph represents data taken by the operator without the benefit of electronic aluminum oxide units. Graph B demonstrates the results when the operator had the use of the electronic units as a guide. Reports by E.I. DuPont de Nemours & Co. (Reference #11 in Section 9.0) and T.W. Moshier (Reference #7) support these observations on the inadequacy of this unit for this application. Serious consideration and effort need to be given to upgrade the Navy standard method of dewpoint monitoring for both high and low pressure systems.

6.1.2 The General Eastern electronically controlled chilled mirror unit showed better repeatability than the Air Dry chilled mirror unit, but did not function well in low moisture ranges (0 - 15 PPMw). The unit continually froze internal components and blew fuses during operation. Graph D in Appendix A illustrates the inadequacy of this unit at such low moisture levels.

6.1.3 The Kahn, Panametrics, DuPont and MCM moisture indicators showed similar trending throughout testing. Graphs A through L in *Appendix A show close tracking, repeatable profiles, and similar* rates of response for these units. In Graph F, only a 10^{o}F difference shows between all units while at the steady-state dewpoint. In this low moisture range, a 10^{o}F difference in dewpoint at 4000 psig represents a difference of less than 0.5 PPMw of moisture. Differences in the actual readings could be attributed to several factors, including differences in sensing technologies (aluminum oxide vs. piezoelectric crystal vs. silicon chip), differences in founding theories (National Bureau of Standards vs. Ideal Gas Laws vs. LDS curves), and the lack of one calibration standard for all the dewpoint indicator units. A report by ORI, Inc. (Reference #12) shows the differences between the three founding theories commonly used and the errors associated with each.

6.1.4 The Pneumetrics dewpoint indicator used during testing employed a thick-filmed aluminum oxide sensor. As can be clearly seen in Graphs C through F in Appendix A, the thick-filmed sensor showed a significant lag in response time to increasing moisture levels as compared to the thin-filmed aluminum oxide sensors such as the Panametrics.

6.2 BREAKTHROUGH

6.2.1 Results repeatedly demonstrated that moisture breakthrough does not occur instantaneously (such as a moisture spike), but occurs as a gradual rise from steady-state to breakthrough dewpoint over an 8 to 10 hour period. This can be seen in Graphs C through F in Appendix A. Based on a normal tower in-service time of 4 hours, 8 to 10 hours is felt to be ample time for corrective action should a move towards breakthrough be detected.

6.2.2 Under normal operating conditions, breakthrough occurred after 40 to 50 hours of continuous operation on a single tower. This is considerably greater than the 4 hour cycle times for which the dehydrator is designed. Phase IV's operating results show breakthrough times ranging from 39 to 53 hours, averaging 45 hours. Further testing would be required to see what effect various non-standard operating conditions would have on these breakthrough times.

6.2.3 Results demonstrated that the dehydrator reaches a steady-state effluent dewpoint after each reactivation. This steady-state dewpoint is illustrated in Graph F in Appendix A. Increased knowledge of this steady-state dewpoint could lead to greater understanding of the dehydrator's performance.

6.2.4 The repeatable trends towards breakthrough shown in Graphs C through F in Appendix A show potential for generating a formula governing dehydrator performance under given conditions. The chances of a dehydrator operator understanding how to use and apply such an equation would depend heavily on prior knowledge of the dehydrator's performance. Knowledge of the system combined with close monitoring would be of greater use to the operator than a formula or equation.

6.3 OIL CONTAMINATION

See Appendix B for quantities of oil extracted during each Phase.

6.3.1 Throughout testing, oil contamination appeared to be a reasonably steady process. Oil aerosols carried-over past CUNO I are the main cause of desiccant degradation in the dehydrator. In Phases I, II and III, a second filter (CUNO II) was used to trap carry-over oil, but in Phases IV and V, only CUNO I was used. In Phases I, II and III, oil quantities past CUNO I consisted of oil found in the CUNO II filters, the flushes of the CUNO II housings, the prefilter and the desiccant. In Phase IV, oil quantities past CUNO I consisted of oil found in the desiccant and the prefilter. In Phase V, only the oil found in the desiccant was considered due to the unsuccessful prefilter extraction, so the average carryover past CUNO I in Phase V should be slightly higher than shown. Results showed comparable amounts of oil carrying-over past CUNO I in all Phases.

CUNO I filter	Phases used	Hours of operation	Oil found in CUNO I filter (g)	Total oil past CUNO I (g)	Average oil carryover past CUNO I (mg/hr)
A	I,II,III	380	23.6	9.824	25.9
B	IV	645	81.8	12.411	19.2
C	V	642	52.3	11.571	18.0

It is interesting to note that in Pnases IV and V, almost the same amount of oil was carried over past CUNO I, even though the CUNO IB filter contained over 50% more oil than CUNO IC. One explanation for the difference in oil quantities found in the CUNO IB and CUNO IC filters in Phases IV and V respectively could be based on their two different operating conditions. The CUNO IC filter sat dormant for 15-16 hours per day. During this time, gravity may have helped the captured oil to coelesce out of the cellulose filter element. CUNO IB in Phase IV did not have these dormant periods, and may not have been able to coelesce out as much oil as CUNO IC.

6.3.2 The AMF CUNO filter element used in CUNO I is rated for 200 hours of operating time. In Phases IV and V, the CUNO I filter was on-line for over 640 hours and did not show signs of performance deterioration. However, average oil carryover past the filter was found to be lower in the longer testing periods. It is important to note that these results are based on a strict blowdown schedule being followed.

6.3.3 In Phase IV, the system operated continuously for 645 hours and gradual oil accumulation in the tower desiccant occurred. Over this time period 13 moisture breakthroughs ccurred on the tower, and results show a gradual decrease in time until breakthrough:

Reactivation	Hours until Breakthrough
0	53
1	47
2	47
3	48
4	48
5	48
6	45
7	43
8	41
9	41
10	39
11	41
12	43

6.3.4 In Phase IV, the steady-state dewpoint gradually increased as oil accumulation continued to degrade the desiccant. For simplicity, only the Panametrics 1000 monitor's readings are shown below, but other indicator readings confirm this gradual rise in steady-state dewpoint:

Reactivation	Steady-state Dewpoint (F)
0	-58
1	-108
2	-108
3	-101
4	-108
5	-108
6	-101
7	-94
8	-94
9	-94
10	-94
11	-94
12	-94

6.3.5 Oil analysis of the desiccant used in Phases IV and V showed an unexpected oil dispersion pattern in the towers. In both Phases, the left tower was in operation for over 90% of the time. The largest concentration of oil was found in the top half of the left tower for both Phases, which is expected since the path for air being dried is in the top of the tower and out the bottom. The next largest concentration of oil was found in the bottom half of the left tower, as was also expected. In the right tower, however, the oil dispersion pattern was opposite to that of the left tower, with the larger oil concentration in the bottom half of the tower and the least amount of oil overall concentrated in the top half of the right tower for both Phases IV and V. These oil analysis results are shown in Appendix B.

6.4 REACTIVATION TEMPERATURES

6.4.1 In Phase V, three moisture breakthroughs occurred after 400°F tower reactivations. The average time until breakthrough was 52 hours and the average drop in dewpoint was 115°F after each reactivation (from +35°F to -80°F). Graph E in Appendix A illustrates the air quality improvement seen after a 400°F reactivation.

6.4.2 Three moisture breakthroughs occurred after 300°F tower reactivations. The average time until breakthrough was 49 hours and the average drop in dewpoint was 100°F after each reactivation (from +35°F to -65°F). Graph I in Appendix A illustrates the air quality improvement seen after a 300°F reactivation.

6.4.3 Three moisture breakthroughs occurred after 200°F tower reactivations. The average time until breakthrough was 33 hours and the average drop in dewpoint was 90°F after each reactivation (from +45°F to -45°F). Graph J in Appendix A illustrates the air quality improvement seen after a 200°F reactivation.

6.4.4 Two moisture breakthroughs occurred after 100°F tower reactivations. The average time until breakthrough was 10 hours and the average drop in dewpoint was only 25°F after each reactivation (from +40°F to +15°F). Graph K in Appendix A illustrates the air quality improvement seen after 100°F reactivations. Note that the dehydrator was no longer able to produce 4 hours of Navy acceptable dry air.

6.4.5 Two ambient temperature reactivations were performed and results showed virtually no air quality improvement. The average drop in dewpoint was only 10°F and the dehydrator was no longer able to produce Navy acceptable dry air. Graph L in Appendix A illustrates the effects of ambient temperature reactivations.

6.4.6 Results indicated a pattern of decreasing hours until breakthrough with lower temperature reactivations. Graph N in Appendix A illustrates these decreasing breakthrough times for the respective reactivation temperatures.

6.4.7 At lower reactivation temperatures, the regenerative capabilities of the dehydrator tower were gradually reduced. Results showed the following average dewpoint temperature drops after the various reactivation temperatures:

Reactivation Temperature (°F)	Drop in Dewpoint Temperature (°F)
400	115
300	100
200	90
100	25
ambient	10

If the heating element was unable to heat the purge air to at least 200°F, the dehydrator could not continue proper operation without replacement/repair of the heater.

6.5 DEHYDRATOR PERFORMANCE

6.5.1 Throughout all Phases of testing, under normal operating conditions the dehydrator produced Navy acceptable quality dry air for periods far in excess of the designed operating cycle of 4 hours. During Phase IV, the dehydrator repeatedly produced dry air for 40 to 50 hour periods before moisture breakthrough occurred.

6.5.2 The high pressure dry air produced by the dehydrator under normal operating conditions was well within the Navy limits for acceptable dry air quality. The dehydrator's effluent air dewpoint usually fell in the -80^{o}F range at 4000 psig. This dewpoint represents a moisture content of less than 1 PPMw, which is well below the Navy maximum allowable moisture content of 15 PPMw.

6.5.3 The majority of maintenance performed on the dehydrator during testing was due to leaks in o-ring seals and valve packings (See Appendix F for notes on maintenance done during testing). The quantity of maintenance on the dehydrator was excessive for a new unit. This excessive maintenance is reflected by high maintenance costs and down-time seen by the Fleet, and the excessive leakage contributes to extended run times of high pressure air compressors

7.0 CONCLUSIONS

Dehydrator performance is influenced by a number of factors. Times to breakthrough and moisture levels at the dehydrator outlet depend on: dehydrator inlet moisture loading, desiccant type and quantity, inlet air temperatures, quantity and composition of contaminents in the air stream, flow velocities, tower design and regeneration effectiveness. The results and conclusions presented were developed with certain variables fixed, such as compressor lubrication rate, separator and filter blowdown frequency and source of purge air. Broad application of this data should only be made to systems operating under conditions similar to those tested.

7.1 DEWPOINT INDICATORS

7.1.1 Dewpoint indicators which rely on a chilled mirror to condense moisture are unsuitable for service at the low moisture levels at which Navy high pressure air systems are designed to operate. These units are not accurate, nor are they repeatable within the 0 to 15 PPMw moisture range.

7.1.2 The Kahn, Panametrics 250 & 1000, MCM Dewluxe and DuPont dewpoint indicator units are able to detect moisture levels of 0 to 15 PPMw, and respond to changes in moisture levels with repeatability and reasonable response times.

7.1.3 The Pneumetrics dewpoint indicator does not have an adequate response time to satisfactorily detect changes in moisture in the 0 to 15 PPMw range. The utilization of the thick-film aluminum oxide sensor as the basis for detecting moisture in this unit produced response times which lagged thin-film sensors by as much as 6 hours.

7.2 BREAKTHROUGH

7.2.1 A steady-state dewpoint is reached after each normal reactivation. Knowledge of how this steady-state dewpoint is effected by various factors (such as system operating conditions or oil accumulation in the desiccant), combined with close monitoring of dehydrator effluent air could lead to a greater understanding of the dehydrator's performance.

7.2.2 Moisture breakthrough on the dehydrator is an orderly process characterized by a smooth, measurable transition from the steady-state dewpoint to unacceptable 'wet' air over an 8 to 10 hour period.

7.2.3 Moisture breakthrough on the dehydrator usually begins 30 to 40 hours after placing a 400^{o}F regenerated tower on-line.

7.3 OIL CONTAMINATION

7.3.1 The CUNO filter is able to steadily remove oil from the compressed air flow for over 600 hours (more than 3 times the rated filter life) with no sign of filter breakdown. Average oil carryover past the filter was found to be lower in the longer testing periods.

7.3.2 The oil accumulation which occurs within the desiccant over time produces a gradual decline in the quantity of moisture the desiccant is able to capture and the quality of air the dehydrator is able to produce.

7.3.3 The quantity of oil needed to significantly impact the dehydrator's output performance is substantially larger than the 11.6 and 11.3 grams collected in the 650 hour Phase IV and V tests (respectively).

7.4 REACTIVATION TEMPERATURES

7.4.1 300°F tower reactivations produce a slight drop in average breakthrough time and output air quality as compared to 400°F reactivations, but still produce Navy acceptable dry air over a limited operating period.

7.4.2 200°F tower reactivations show a further drop in average breakthrough time and output air quality but still produce Navy acceptable dry air over a limited operating period.

7.4.3 100°F tower reactivations show a significant decline in breakthrough times and output air quality, and failed to produce 4 hours of Navy acceptable dry air.

7.4.4 Ambient temperature reactivations show virtually no regenerative capabilities and will not produce Navy acceptable dry air.

7.4.5 Reactivation temperatures below 200°F are not adequate for dehydrator operation.

7.4.6 Reactivation temperatures between 200°F and 400°F are adequate for short-term dehydrator operation, and may be adequate for full tower regenerations for long-term operation.

7.5 DEHYDRATOR PERFORMANCE

7.5.1 Under the outlined operating conditions, the dehydrator repeatedly produced Navy acceptable quality dry air for periods far in excess of the designed operating cycle (40 hours of acceptable air vice 4 hour operating cycles).

7.5.2 Dehydrator steady-state output air quality far exceeded Navy criteria for acceptable dry air (-80°F dewpoint at 4000 psig is less than 1 PPMw vice 15 PPMw maximum Navy allowable).

7.5.3 Maintenance to the dehydrator was driven by numerous leaks in o-ring seals and valve packings. The quantity of maintenance was excessive, and in the Fleet these excessive leaks contribute to extended run time of high pressure compressors.

8.0 RECOMMENDATIONS

8.1 DEWPOINT MONITORING TECHNOLOGY

Recommend that serious consideration be given to investigating state-of-the-art dewpoint measurement technologies (such as silicon chip sensors) as the new Navy standard. Efforts to adopt older technologies (such as aluminum oxide sensors) will only continue to put out-dated equipment in the Fleet. The technology of dewpoint indicators (hygrometers) has developed substantially from the 1950/60 optical chilled mirror (the current Navy standard).

8.2 NAVY DEWPOINT INDICATOR CALIBRATION

Recommend Navy METCAL program evaluate ability to calibrate dewpoint indicators in the 0 to 35 PPMw moisture range.

8.3 DEHYDRATOR O-RINGS

Recommend design improvements in o-rings used in the dehydrator. Repeated o-ring failures occurred due to poor design and improper material.

8.4 FUTURE TESTING

8.4.1 Recommend testing full-flow dehydrator capacity by operating two compressors on one dehydrator and observing effects on dehydrator capabilities.

8.4.2 Recommend long-term reduced reactivation temperature testing to observe effects on dehydrator's capabilities for extended periods.

8.4.3 Recommend testing of restricted purge flows during reactivation to observe effects on dehydrator's regenerative capabilities.

8.4.4 Recommend testing to observe the effects of failure to follow the system's drain blow-down schedule.

8.4.5 Recommend testing to observe effects of various system backpressures on dehydrator's performance.

8.4.6 Recommend testing to observe effects of severe desiccant degradation (due to excessive oil contamination) on dehydrator capabilities.

9.0 REFERENCES

1. NAVSEA S9SSN-W4-SSM-330 (688 Class SIB) Vol 4, Pt 1, Ch 1 High Pressure Air System

2. NAVSEA S9SSN-XT-SSM-340 (688 Class SIB) Vol 4, Pt 1, Ch 2 Service Air Systems

3. NAVSEA S9551-A9-MMM-010 Original Dehydrator, Desiccant, Semi-Automatic, High Pressure Air, Model 10101-7 Manufactured by Air Dry Corporation, Northridge, CA FSCM 01496

4. NAVSHIPS 0949-003-6000 High Pressure Class AA Air Compressor (Submarine Service) 13.0 CFH @ 4500 psi 440 VAC Motor, Manufactured by Worthington Corporation, Buffalo, NY FSCM 93236

5. NAVSEA SN540-AD-MMO-010 High Pressure Frost/Dewpoint indicator, Model 10310-24 Manufactured by Air Dry Corporation, Northridge, CA FSCM 01496

6. Military Standard; MIL-STD-1622A (SH) Cleaning of Shipboard Compressed Air Systems

7. Investigation into Adverse Dehydrator Discharge Air Dew Points Associated with Dehydrators Per NAVSHIPS Technical Manuals #349-0678 and #338-0512 by T.W. Moshier of SSBN SMMSO NAVSEC Hyattsville, MD of 1975

8. Ships Systems ISE Advisory No 085-83 Dry Air Systems Desiccant Procurement and Installation Thereof NAVSSES Philadelphia, PA MSG 062049Z Dec 83

9. NEES Progress Report 620629D The Removal of Lubricating Fluids From High Pressure Air; S-F130814-1070, U.S. Naval Engineering Experiment Station Annapolis, MD

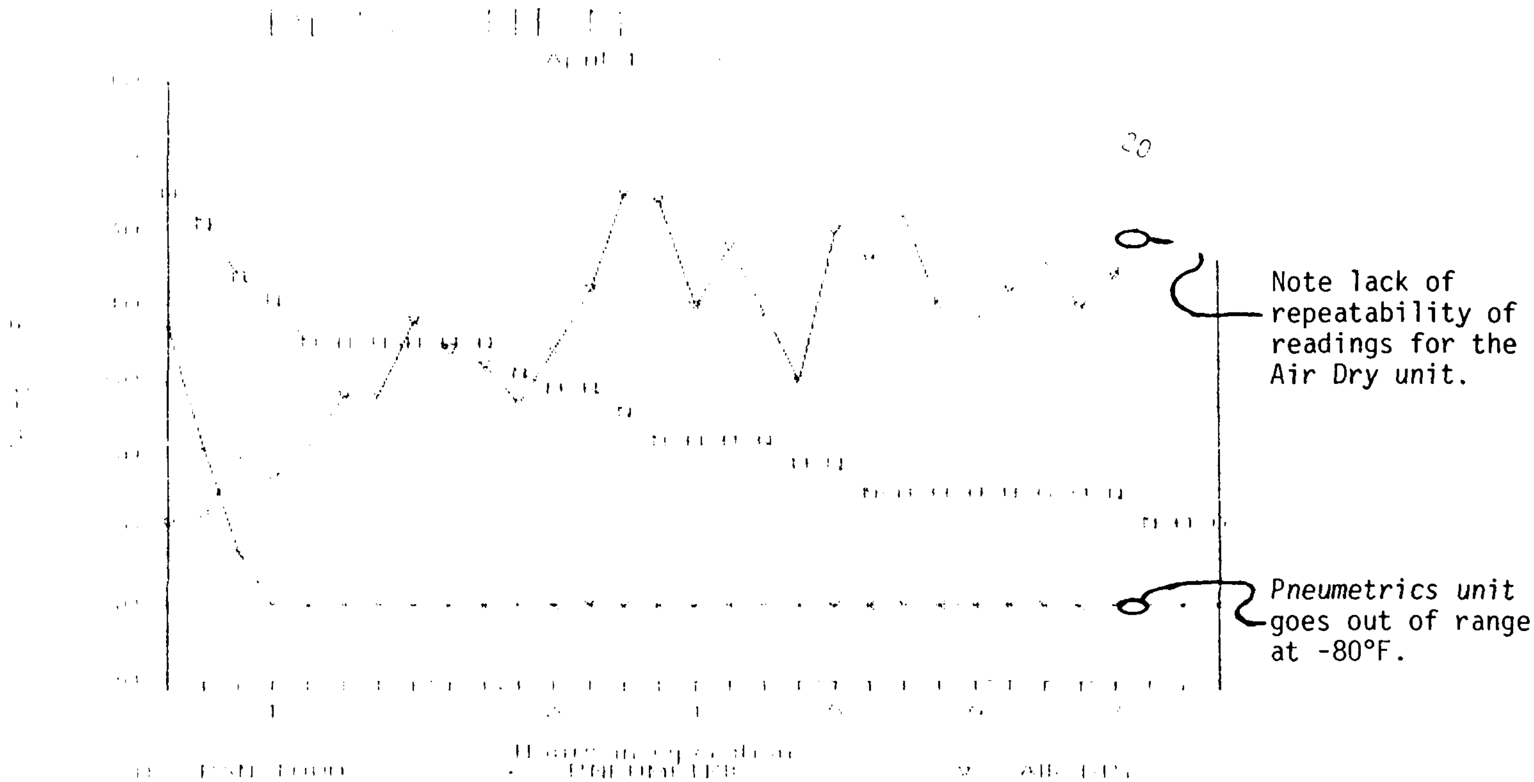
10. Martin Marietta Energy Systems, Inc. Dewpoint/Frostpoint Monitoring Equipment for Ship's Service Pressurized Air of 26 May 1987

11. E.I. DuPont de Nemours & Co. (Inc.) An Analysis of the Moisture Content of the Norfolk Naval Shipyard High Pressure Air Supply by C.B. Blakemore and J.C. Steicher of August 1986

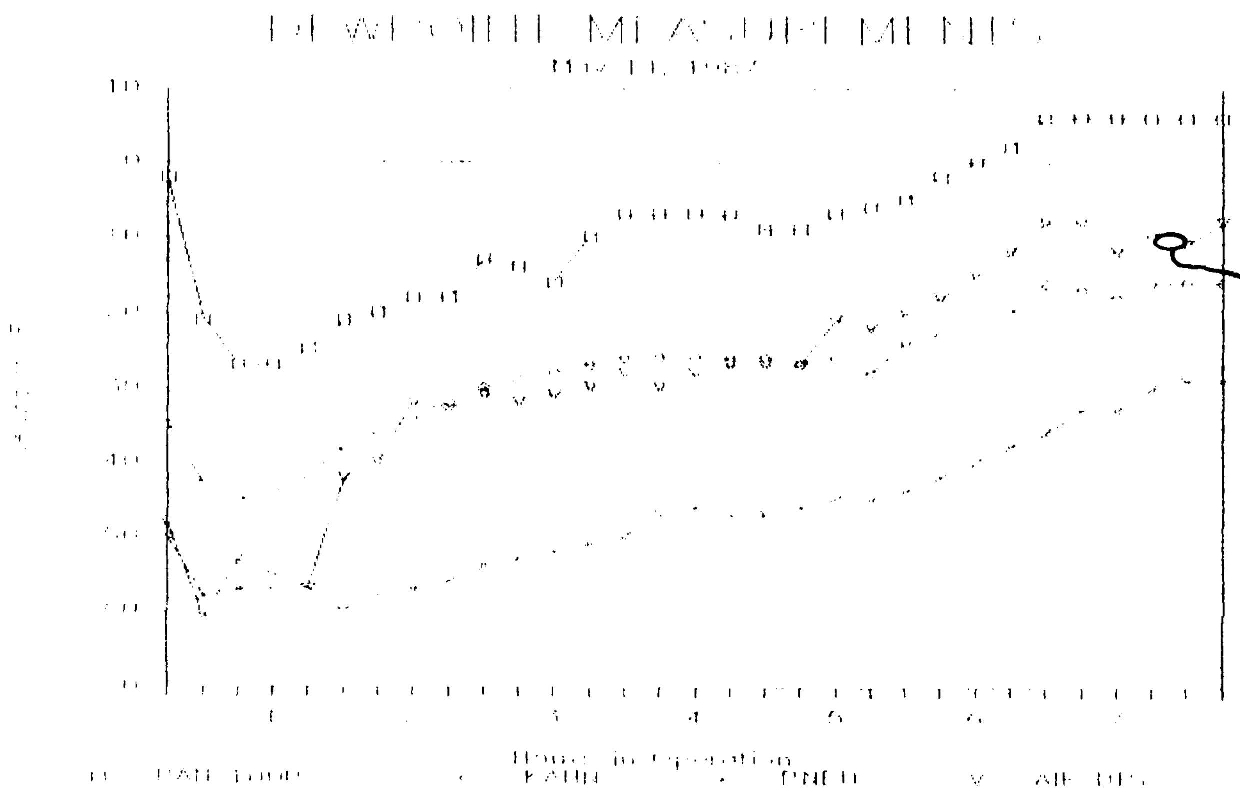
12. ORI Inc. High Pressure Air Dewpoint Review by G. Nelson and T. Hatala of September 1985. Prepared for NAVSEA 05N under contract number N00024-33-C-2111.

13. General Dynamics Corporation, High Pressure Air Filtration Report by M.P. Wilson, Jr., F. DeSouza, and J. Presti of 28 February 1962. Prepared for DTIC.

14. NAVSEA 0901-LP-490-0003 Chapter 9490 Change 10 of April 15, 1984 Compressed Air Plant Systems.

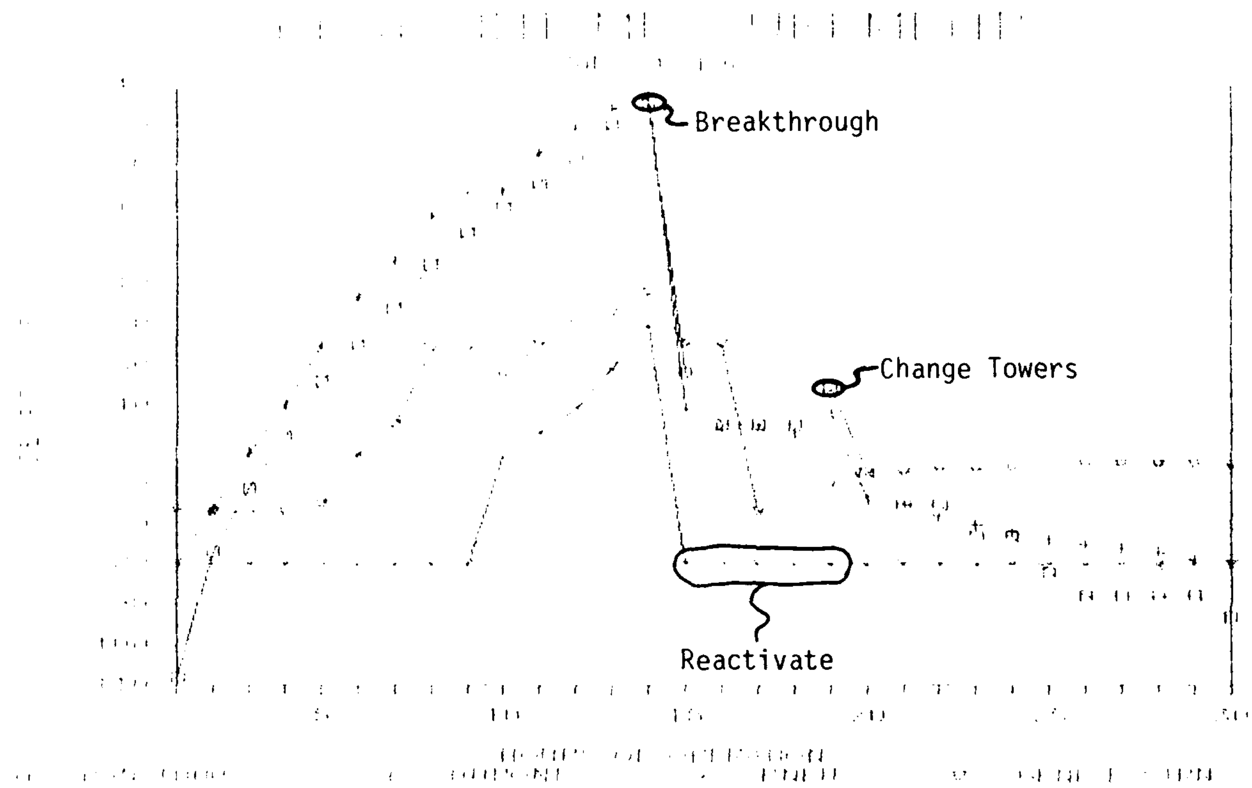


GRAPH A - PHASE I



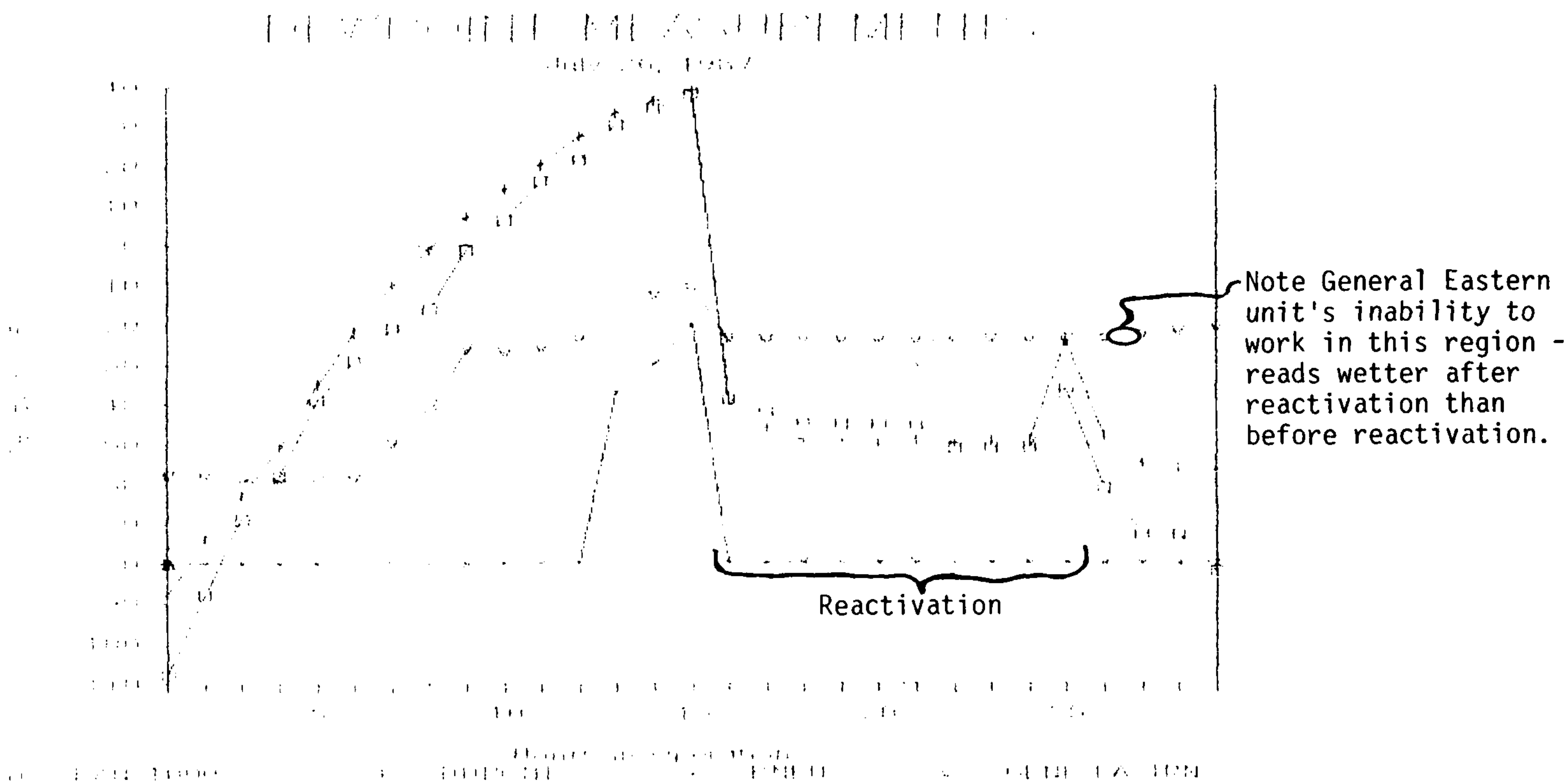
Note operator's use of electrical units as a guide for the Air Dry unit.

GRAPH B - PHASE I



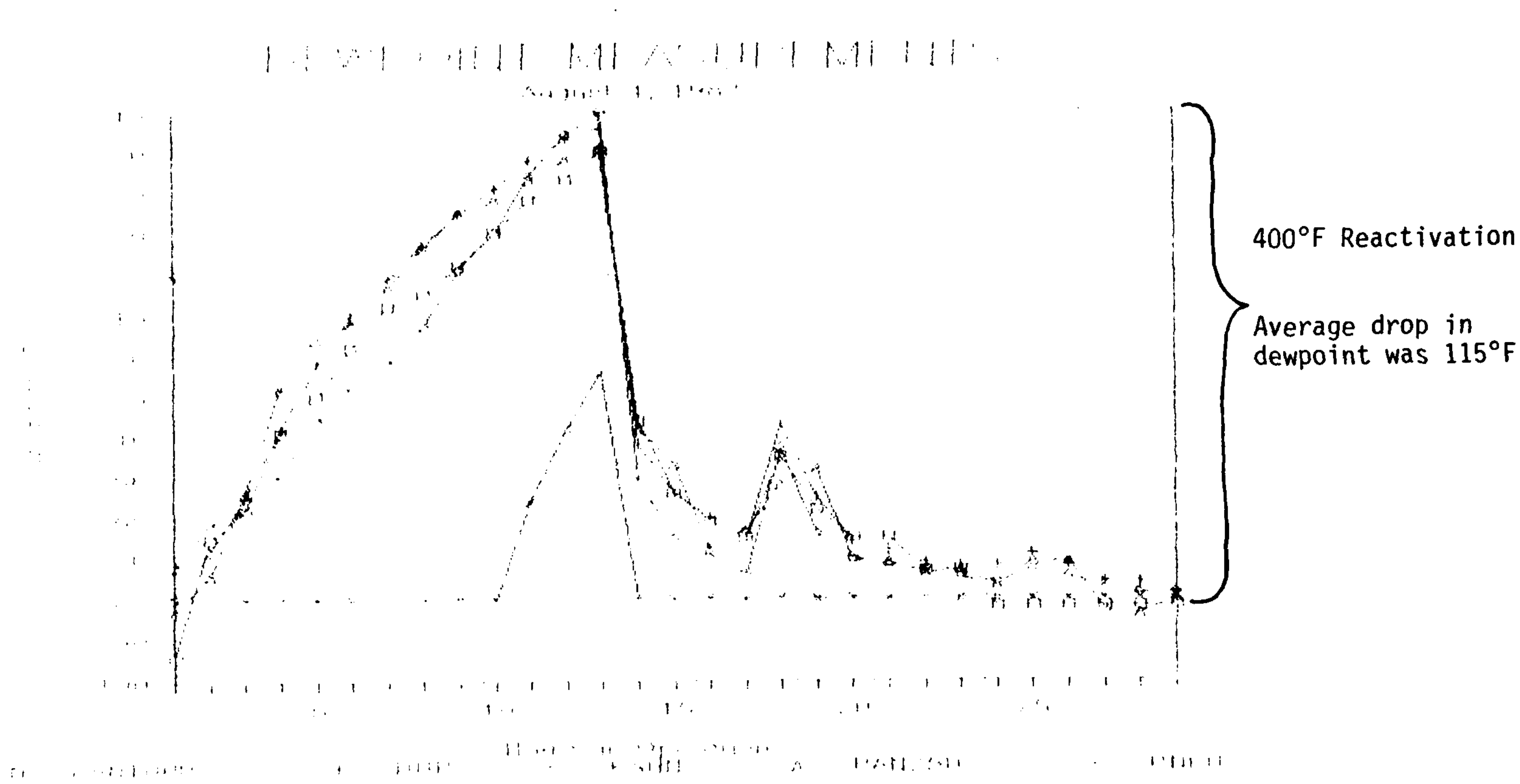
Note how closely the Panametrics 1000 and DuPont units track, even though two different sensors, pressures, and technologies are used.

GRAPH C - PHASE IV



Note the repeatable profiles in Graphs C & D

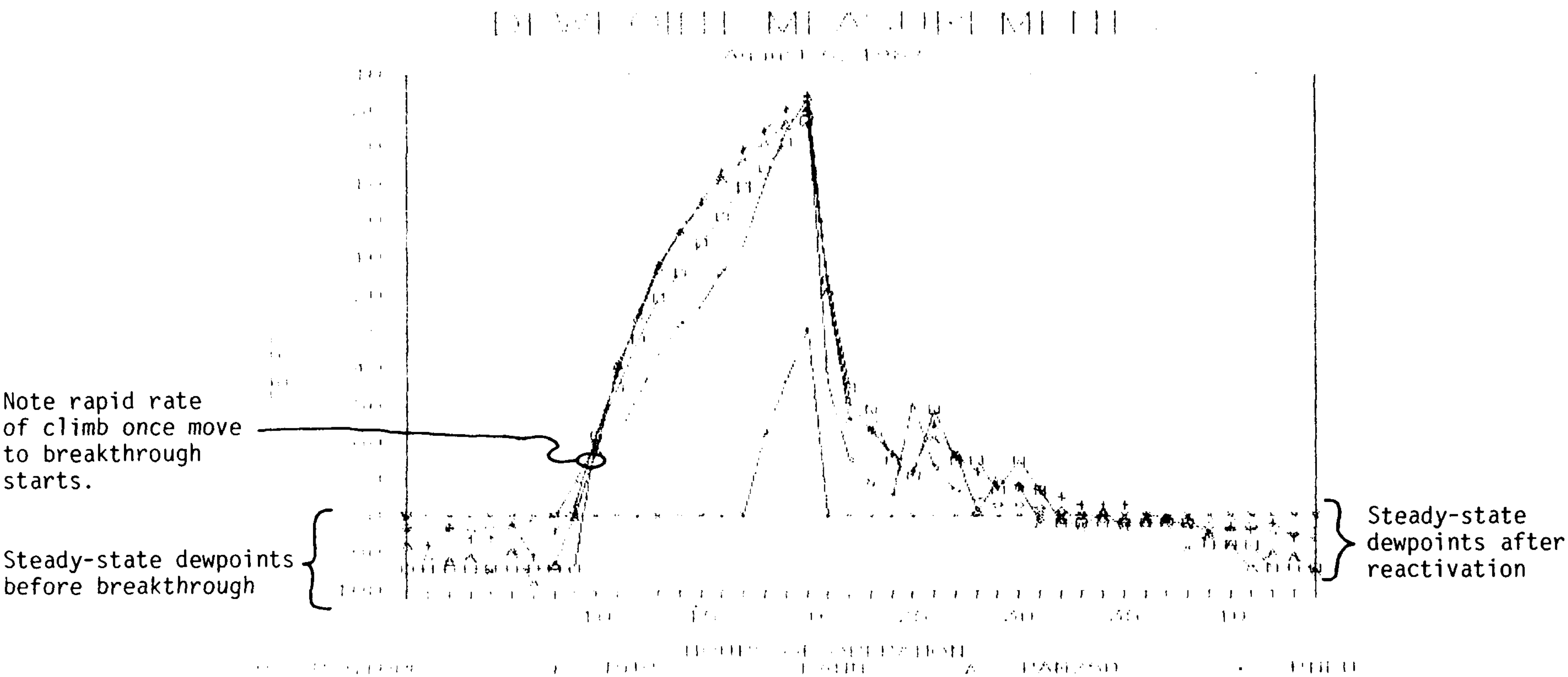
GRAPH D - PHASE IV



Two more close-tracking units added: Kahn and Panametrics 250

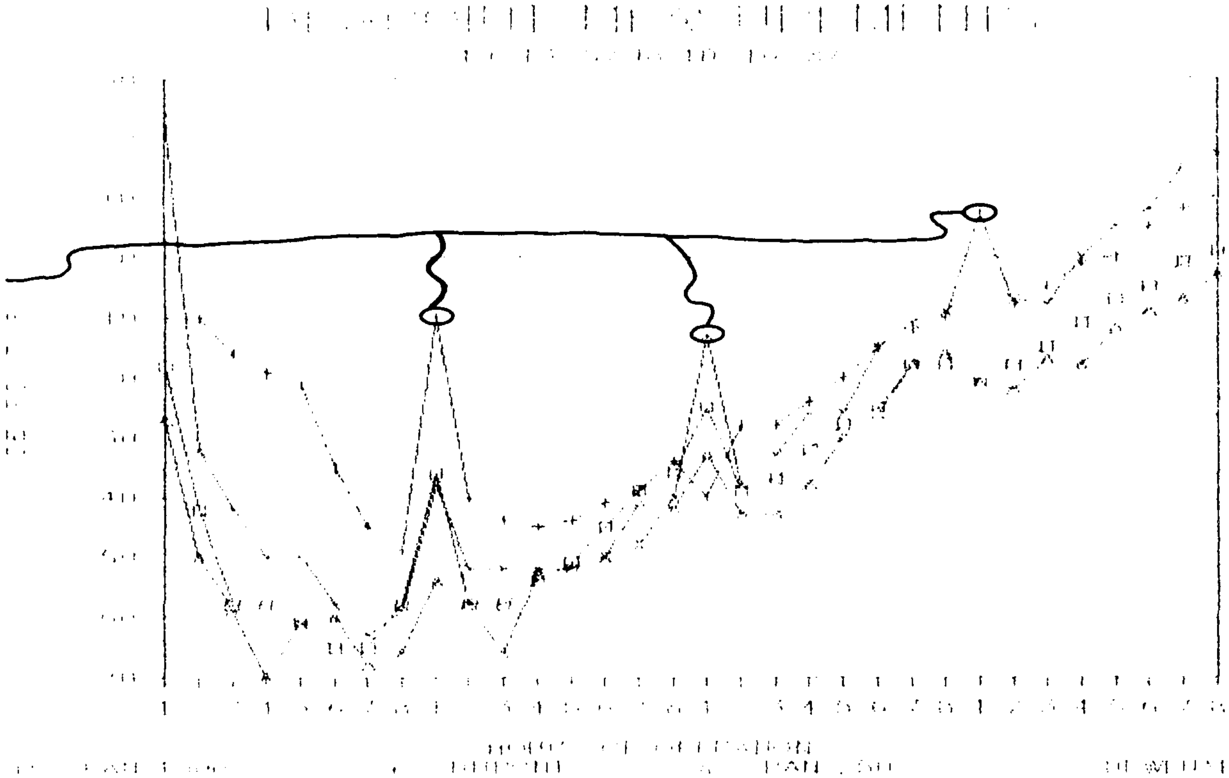
Note again the repeatable profile

GRAPH E - PHASE IV



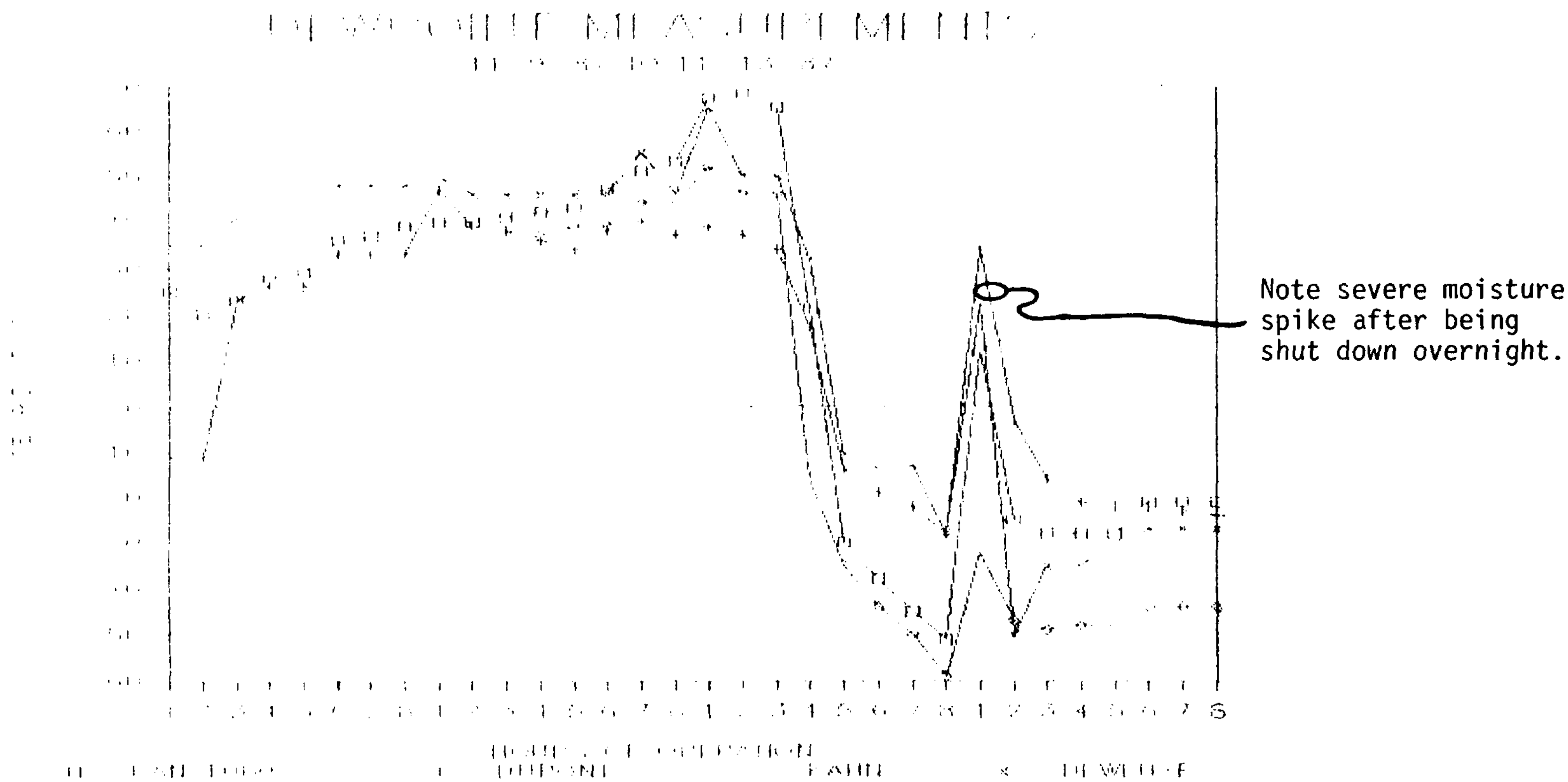
GRAPH F - PHASE IV

Note tendency for
moisture spike
after being shut
down overnight.



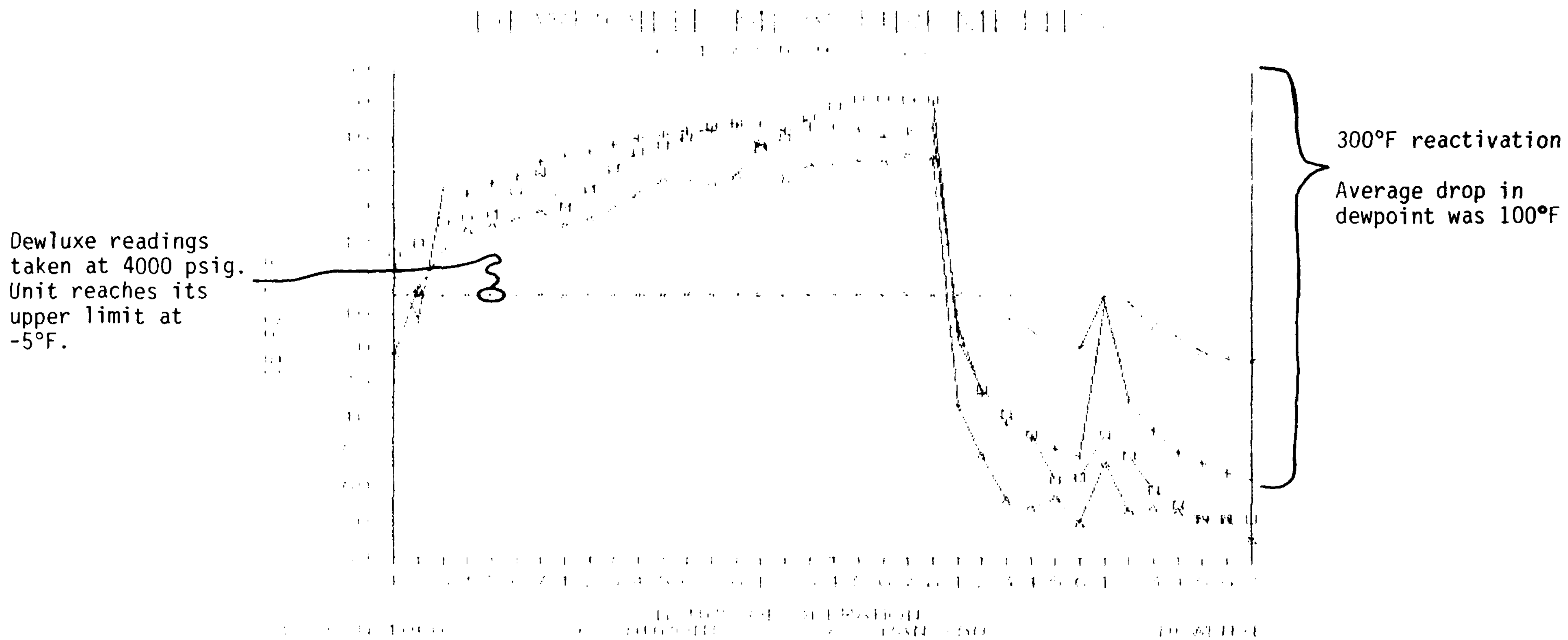
Note similar profiles for all units.

GRAPH G - PHASE V

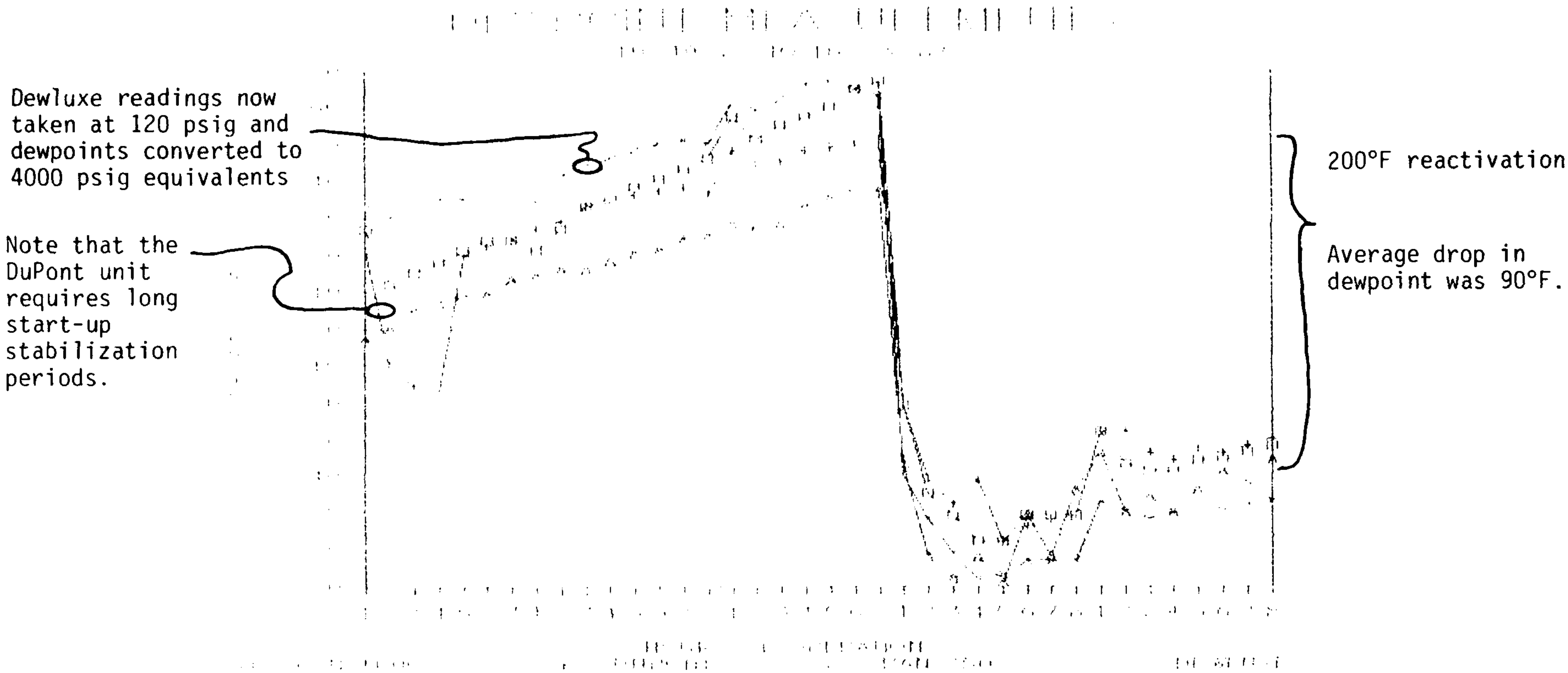


Note removal of Panametrics 250 unit and addition of Kahn unit - all units still show similar profiles.

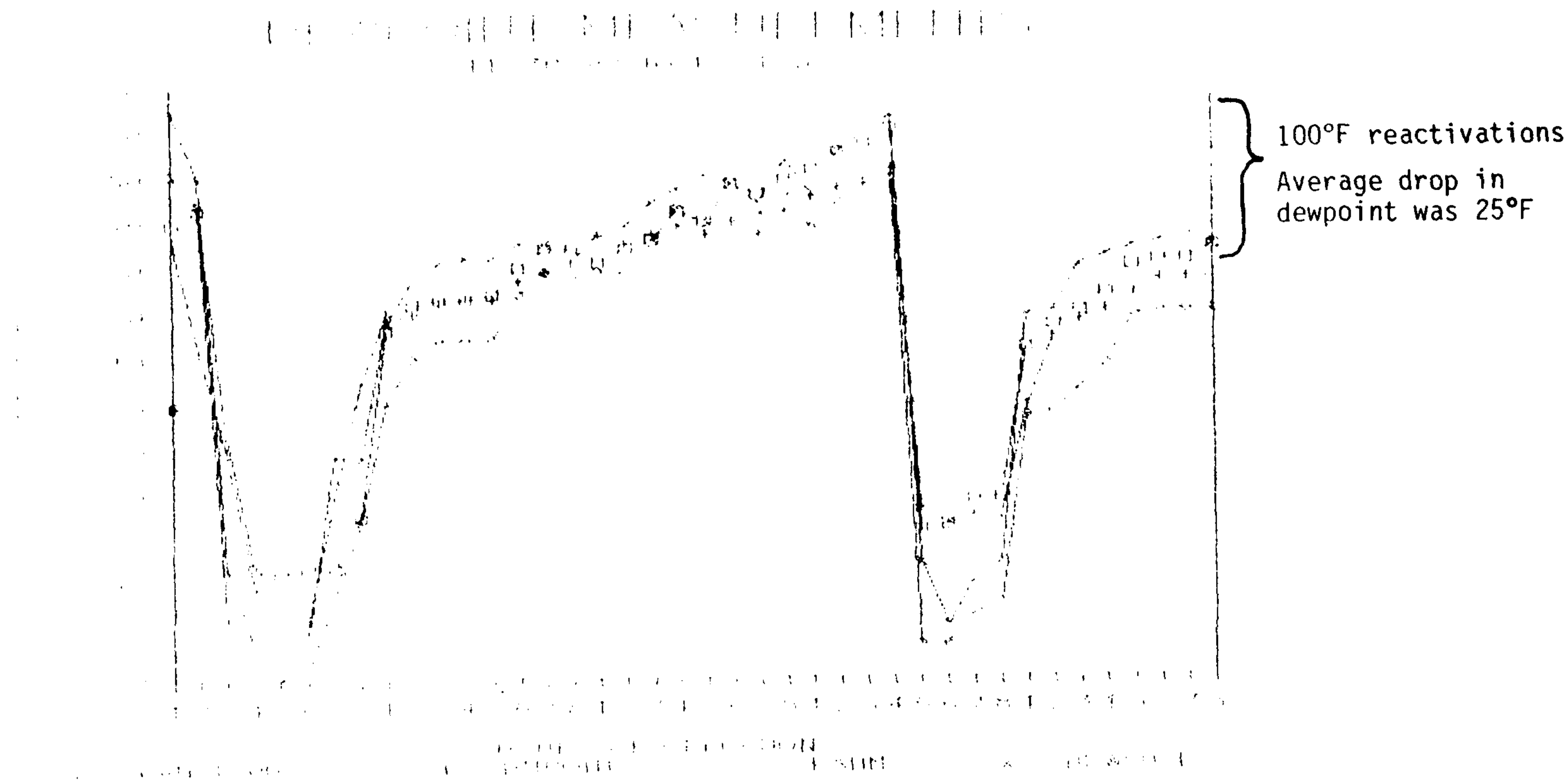
GRAPH H - PHASE V



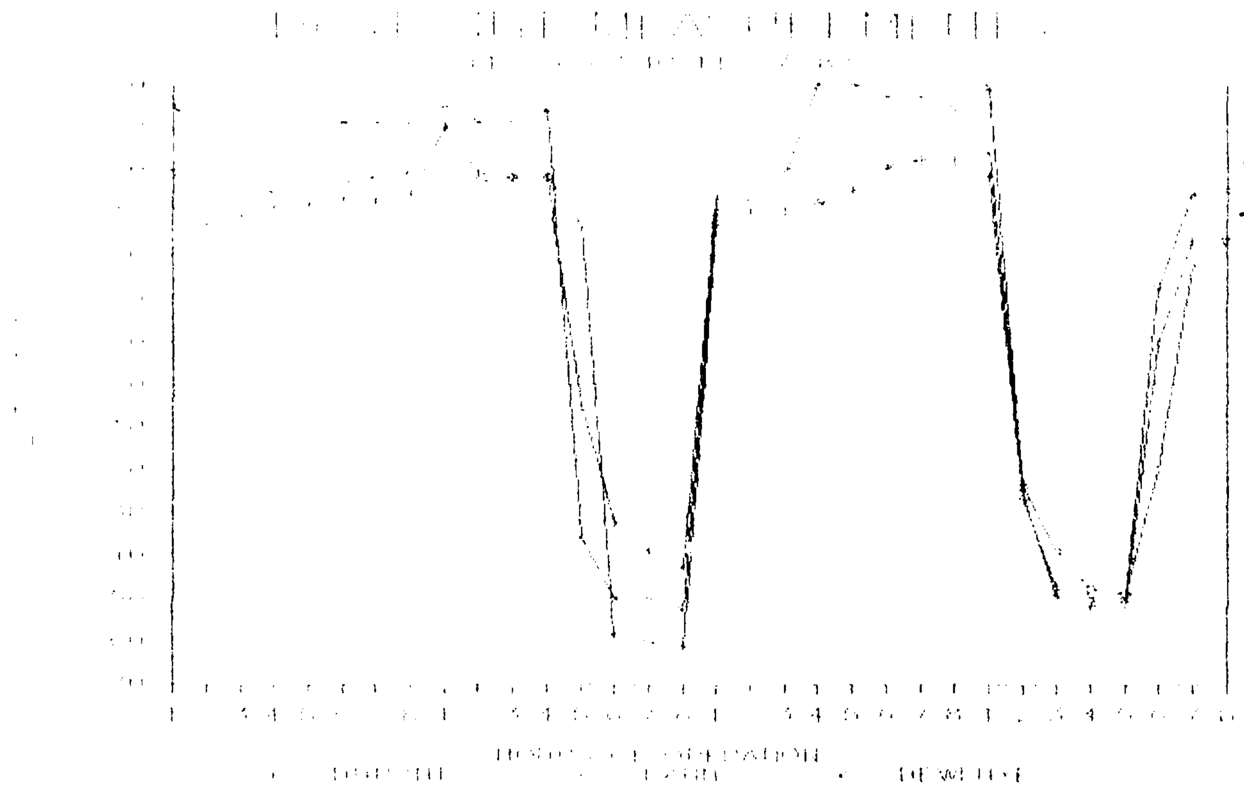
GRAPH I - PHASE V



GRAPH J - PHASE V



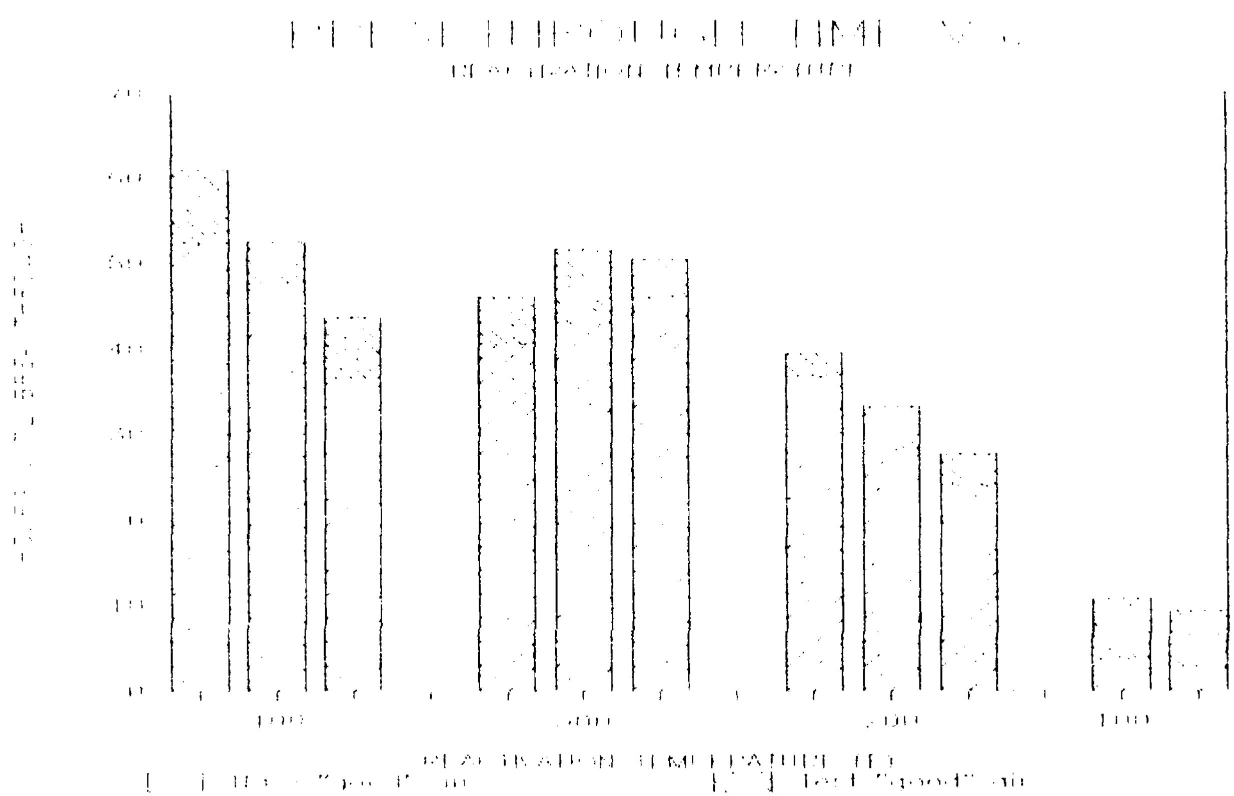
GRAPH K - PHASE V



Ambient temperature
reactivations

Average drop in
dewpoint was 10°F

GRAPH L - PHASE V



(dewpoint better than
+20°F at 4000 psig)

(dewpoint better than
+35°F at 4000 psig)

GRAPH M - PHASE V

APPENDIX B

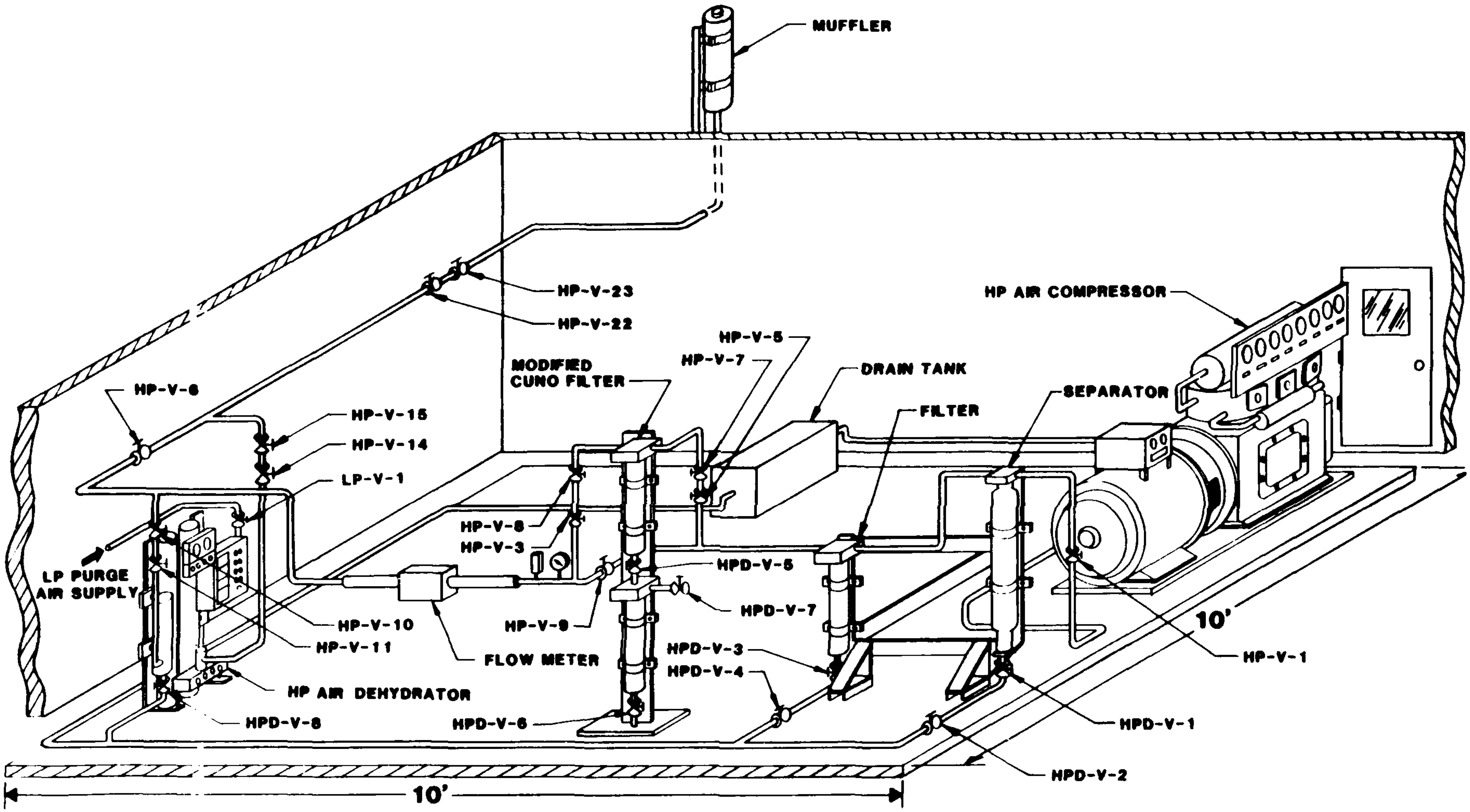
PHASES I - V OIL EXTRACTION RESULTS

TABLE 1: PHASES I - V OIL EXTRACTION RESULTS

Sample	Grams of oil	Phase
CUNO II Housing	0.332	Phase I (156 Hrs)
CUNO III Housing	0.313	
Prefilter	0.144	
CUNO IIA Filter	1.369	
Left Tower Desiccant	0.426	
Right Tower Desiccant	1.174	
CUNO II Housing	0.048	Phase II (78 Hrs)
CUNO IIB Filter	1.266	
CUNO I Housing	0.960	Phase III (146 Hrs)
CUNO II Housing	0.300	
CUNO IA Filter	23.632	
CUNO IIC Filter	1.531	
Left Tower Desiccant	2.268	
Right Tower Desiccant	0.797	
CUNO I Housing	0.484	Phase IV (645 Hrs)
CUNO IB Filter	81.803	
Prefilter	1.099	
Left Tower Desiccant Upper Half	7.667	
Left Tower Desiccant Lower Half	3.218	
Right Tower Desiccant Upper Half	0.098	
Right Tower Desiccant Lower Half	0.329	
CUNO I Housing	4.465	Phase V (642 Hrs)
CUNO IC Filter	52.286	
Prefilter	unsuccessful	
Left Tower Desiccant Upper Half	6.603	
Left Tower Desiccant Lower Half	3.111	
Right Tower Desiccant Upper Half	0.642	
Right Tower Desiccant Lower Half	1.215	

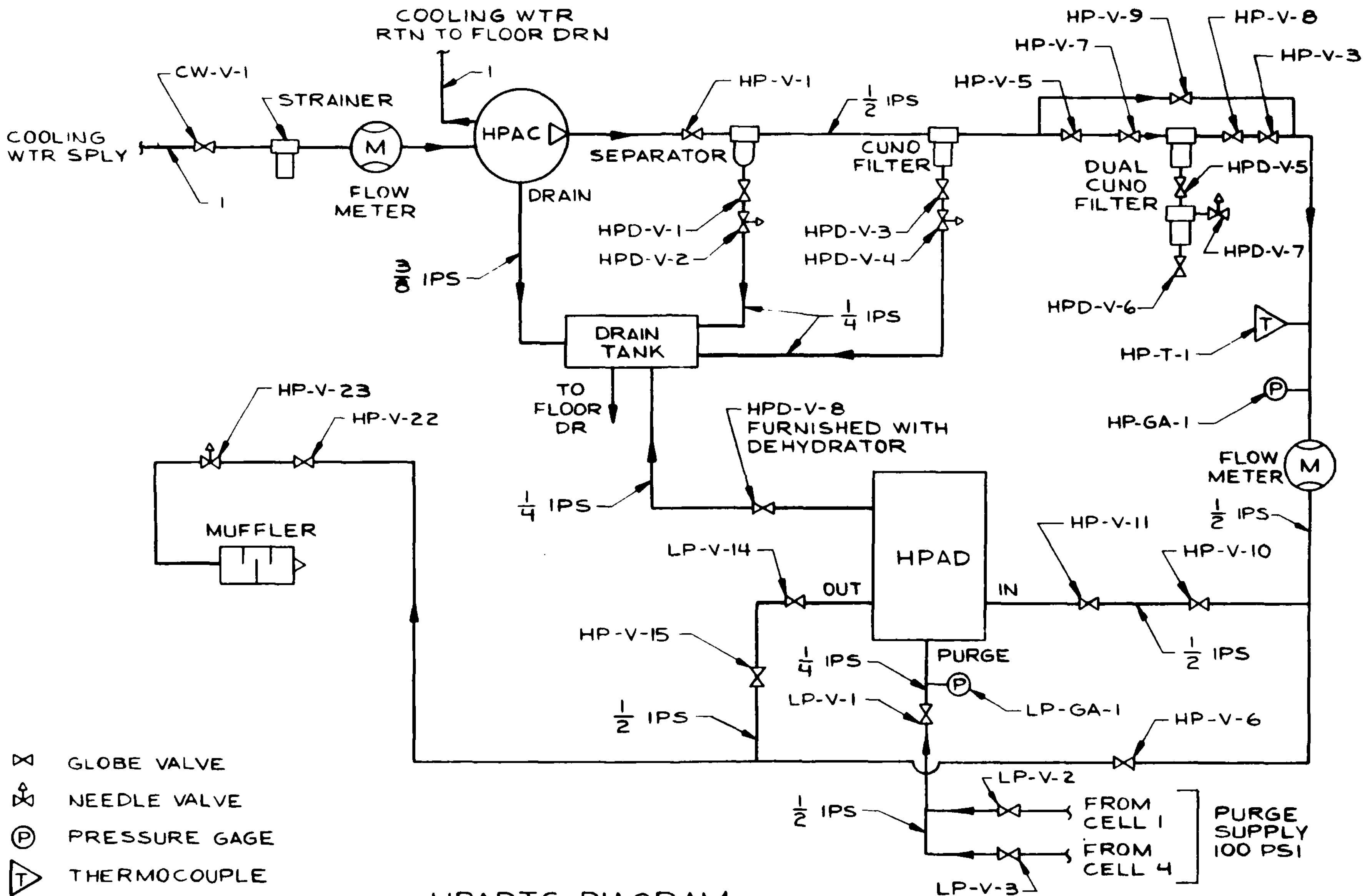
APPENDIX C

DESCRIPTION OF SYSTEM COMPONENTS



HIGH PRESSURE AIR DEHYDRATOR TEST STAND (HPADTS)

FIGURE C-1



HPADTS DIAGRAM

SKETCH # 5512-006-1

FIGURE C-2

DATE: 10/24/86

WORTHINGTON HPAC
SERIAL: L68938

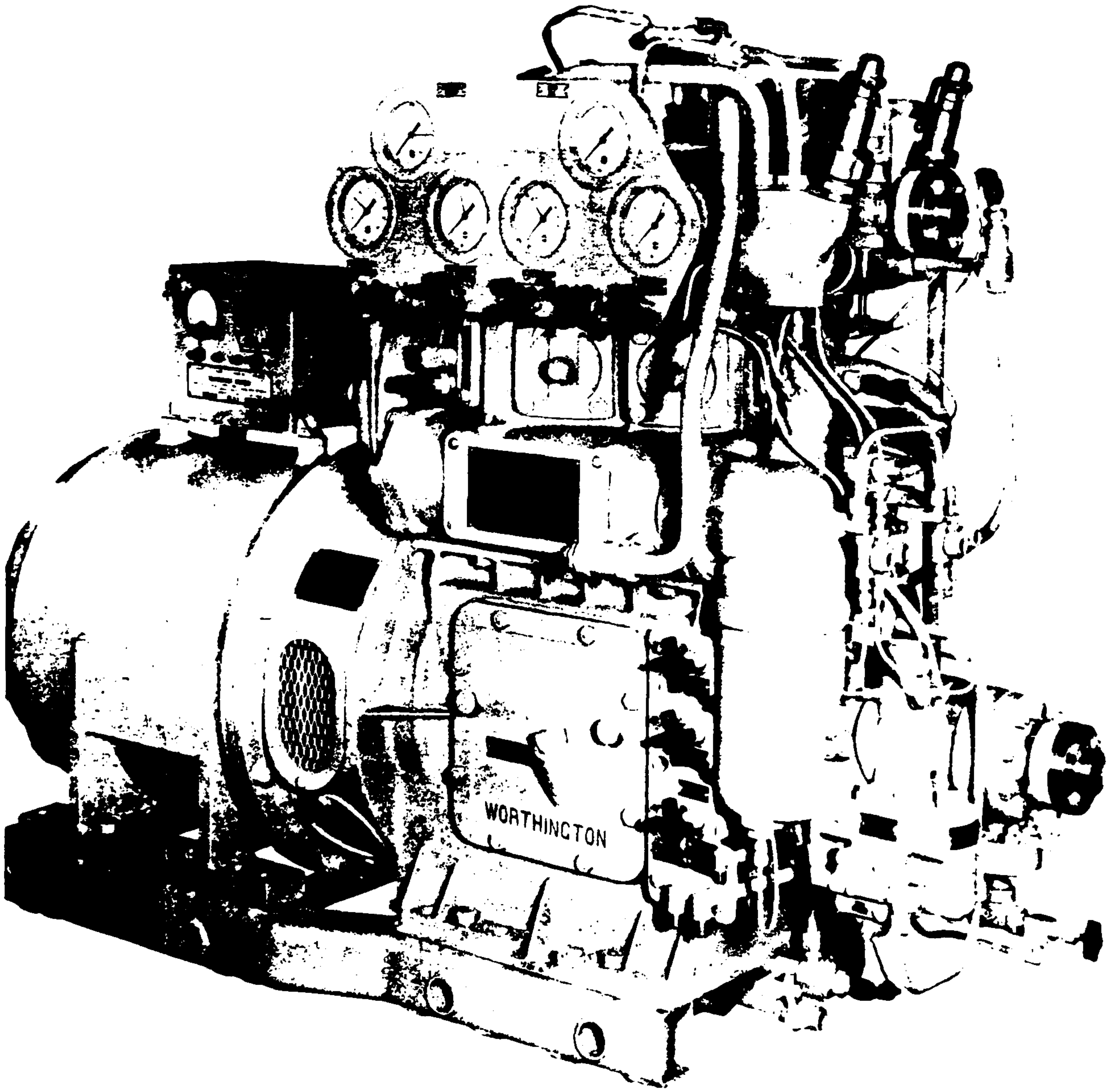


Figure C-3

TABLE 2

Worthington HPAC Reference Data

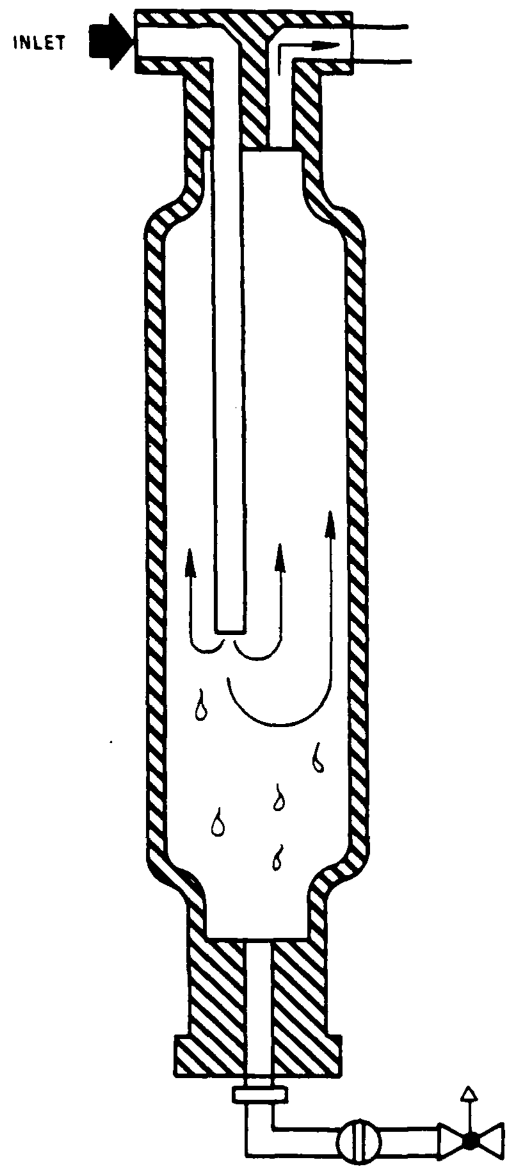
COMPRESSOR DATA	
Compressor Size	7-1/4" & 4-3/8" & 1-3/4" & 1" x 5"
Stages	Four
Cylinder Arrangement	Vertical, Single Acting, Different al
Service	Hi-Shock
Rated Discharge Pressure	4500 psi (Design Condition)
Maximum Overload Pressure	5000 psi (Design Condition)
Suction Temperature	122° (Design Condition)
Relative Humidity	50% (Design Condition)
Cooling Water Temperature	85°F (Design Condition)
Brake Horsepower--Full Load	47 HP
Speed--Normal	900 rpm
Speed--Full Load	870-875 rpm
Piston Speed--Nominal	750 feet per minute
Piston Speed--Full Load	729 feet per minute
Displacement	194.4 cu. in.
Displacement--Nominal	101.4 cu. ft. per min.
Displacement--@ Full Load Speed	98.5 cu. ft. per min.
Volumetric Efficiency	63.8% @ 4500 psi discharge
Free Air Capacity @ Design Conditions	63.2 cu. ft. per min.
Rated Delivery Capacity	13.0 cu. ft. per hour @ 4500 psi
Rated Delivery Capacity	12.0 cu. ft. per hour @ 5000 psi
Cooling Medium	Sea Water
Cooling Water Rate @ Design Conditions	15 gpm minimum
Cooling Water Pump Gear Ratio	4:1
Cooling Water Pump Full Load Speed	3500 rpm
Water Pump TDH @ 3400 RPM & 15 GPM	21 psi
Cooling System Pressure Drop Through Compressor	12 psi @ rated flow
Allowable External System Loss	9 psi (lift & head & line drop)
Cooling Water Pressure	500 psi max.
Cooler Surface Area--1st or 2nd Stage	8.7 sq. ft. each
Cooler Surface Area--3rd Stage	3.54 sq. ft.
Cooler Surface Area--4th Stage	2.75 sq. ft.
Crankpin Bearing Pressure	820 psi, projected area
Crankpin Surface Speed	645 ft. per min.
Hydrostatic Test Pressures:	
1st Stage Cylinder, Cooler & Piping	75 psi (air side)
2nd Stage Cylinder, Cooler & Piping	400 psi (air side)
3rd Stage Cylinder, Cooler & Piping	1700 psi (air side)
4th Stage Cylinder, Cooler & Piping	7500 psi (air side)
All Cylinders, Coolers & Piping	500 psi (water side)

PRESSURE SETTINGS			
	Gage Red Hand Settings		Relief Valve Release Settings
	@ 4500 psi	@ 5000 psi	
1st Stage	45 psi	45 psi	60 psi
2nd Stage	265 psi	270 psi	330 psi
3rd Stage	1120 psi	1190 psi	1225 psi
4th Stage	4500 psi	5000 psi	5100 psi
Cooling Water	500 psi	500 psi	500 psi
Lubricating Oil	50 psi	50 psi	50 psi (hot)

COMPONENT LIST			
Component	Manufacturer	Principal Dimensions	Weight (Approx.)
Compressor	Worthington Corp.	5'7-11/16" x 2'5-3/4" x 4'2"	1665 lbs.
Temperature Monitor	Thomas A. Edison, Inc.	12-1/2" x 7-1/4" x 9"	25 lbs.
Motor	Electro Dynamic	2'7-1/16" x 2'4-1/4" x 2'1-1/4"	1150 lbs.
Pressure Switch	Detroit Controls Corp.	11-5/8" x 7" x 2-3/4"	9 lbs.
Separator Drain System	Worthington Corp.	19-1/8" x 18-11/16" x 17"	195 lbs.

Cap: .5 cu ft

Type: Non Shatterable
Manf: US Steel
NSN: 9C-4220-01-190-3836



MOISTURE SEPARATOR

Figure C-4

CUNO FILTERS

AMC CUNO DIV.
AMF INCORPORATED
402 RESEARCH PKY
MERIDEN CONN. 06450
FSCM: 15472
(203) 237-5541

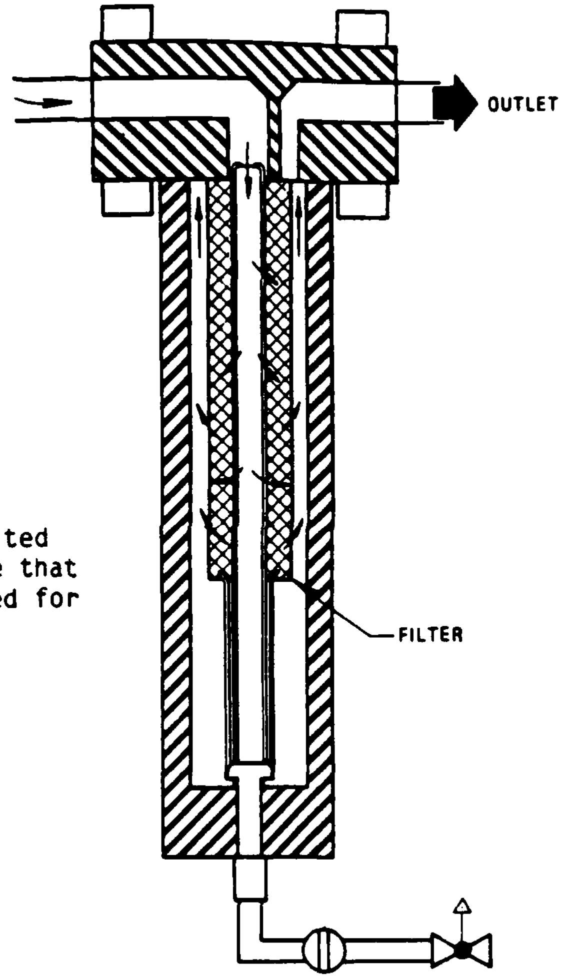
CAT; 40382-02
MODEL: 1H1
OPER: 5000 PSI
ELEMENT: U78B2
APL: 480060326
FILTER NSN: 9C-4330-008113839
O'RING NSN: 9Z-5330-005841948
ELEMENT TYPE: Graded density, felted cellulose cartridge that is resin impregnated for body strength

OVERALL DIMENSIONS
HOUSING

Weight Approx = 120 lbs
Height = 21"
Sq. Flange = 8 1/2 on side

FILTER ELEMENTS

Cellulose Fiber
Length = 9 3/4"
Dia. = 2 3/4"



CUNO FILTER MODEL 1H1
(CUNO I)

Figure C-5

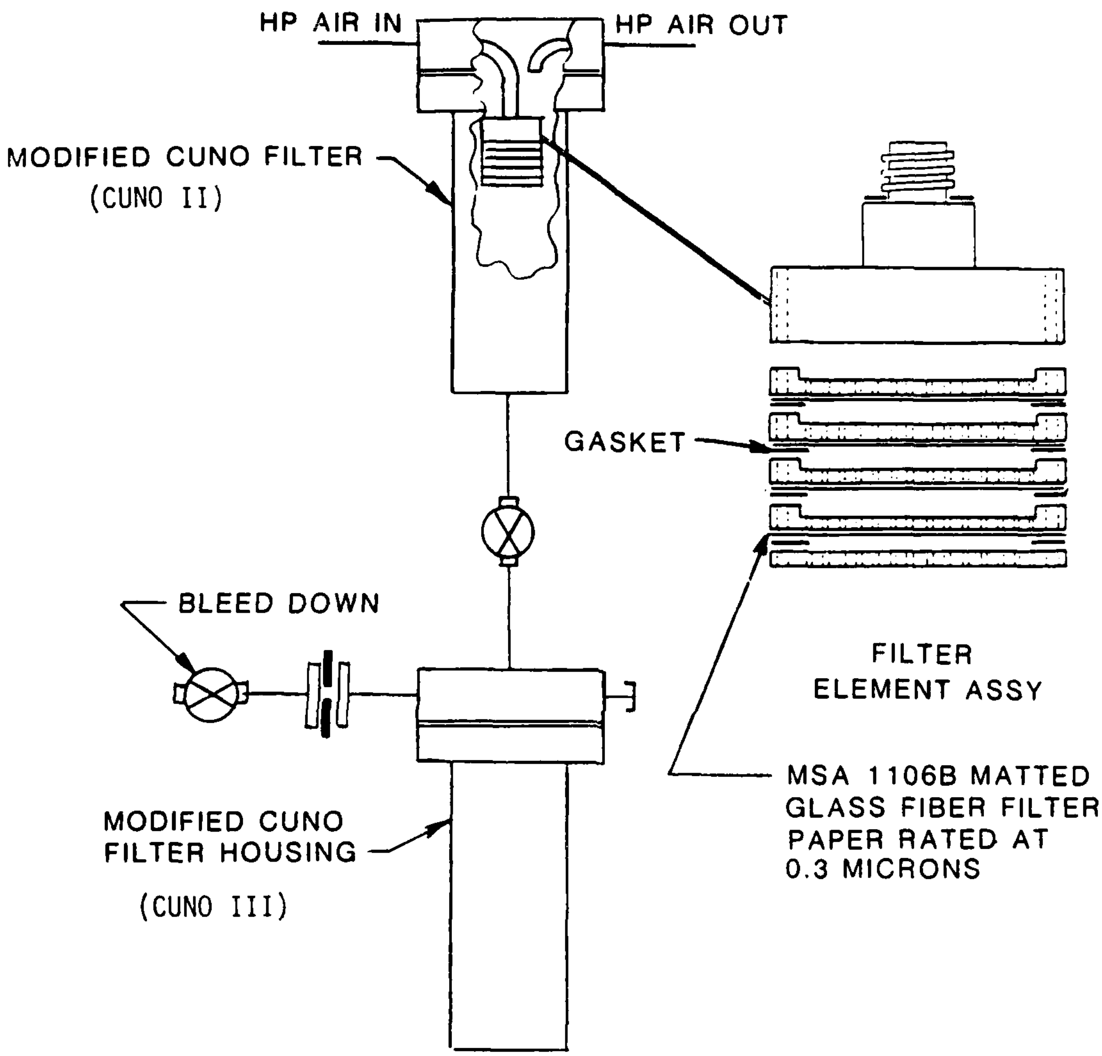
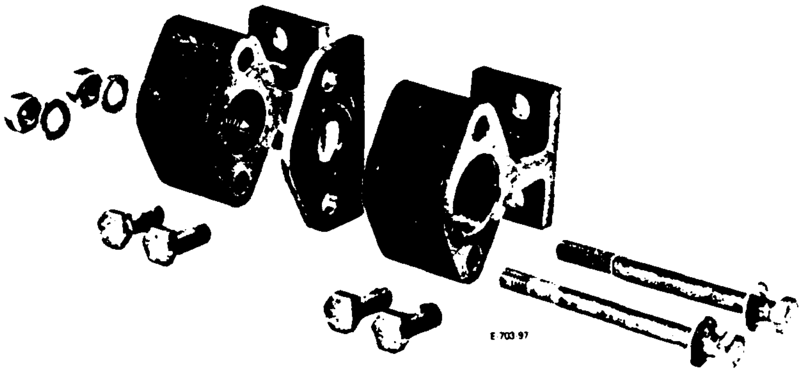


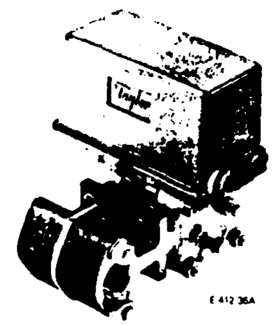
Figure C-6

MODIFIED CUNO FILTER HOUSING

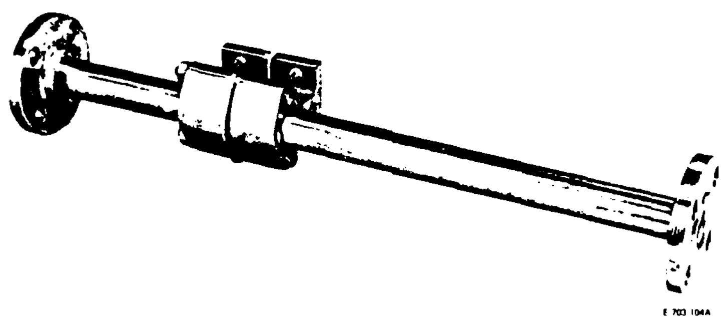
INTEGRAL ORIFICE FLOW ELEMENT
1 in. and 1½ in. NPT SIZES



Exploded View: Note the design simplicity.



Transmitter
with Integral Orifice Mounted



1330L Integral Orifice
with Welded Upstream and Downstream Piping

PRODUCT DESCRIPTION

The Integral Orifice is a flow element capable of being close coupled with Taylor differential pressure transmitters to make a complete, compact, flow-metering-transmitting assembly. The Integral Orifice provides easier, lower cost installation for handling small flows found frequently in plant metering operations and research projects. It is available in sizes 1 inch and 1½ inch with both threaded and welded pipe run flanged-end constructions. The 1330L cannot be mounted on the transmitter at the factory. It must be shipped as a *separate item*.

FEATURES	BENEFITS
• Easily fitted to process line	Simplified installation
• *Accurate flow measurement*	Laboratory calibration not required
• Flanged construction	Standardized face-to-face dimension
• Wide variety of standard bores	Quick delivery from stock

SPECIFICATIONS

FUNCTIONAL CHARACTERISTICS

Accuracy

Uncalibrated Orifice Bores	0.020 – 0.065 ± 5% of rate 0.113 – 0.500 ± 2% of rate 0.612 – 1.127 ± 1.5% of rate
Calibrated in Taylor Flow Laboratory	± ½ % of rate

Pressure Rating

Threaded	1 in. NPT 3000 psig (21 000 kPa) at 300°F (150°C) 1 ½ in. NPT 1500 psig (10 500 kPa) at 300°F (150°C)
Flanged	Class 150 ANSI - 275 psig MWP (1900 kPA) at 100°F (38°C) Class 300 ANSI - 720 psig MWP (5000 kPa) at 100 °F (38°C)

PHYSICAL CHARACTERISTICS

Materials of Construction

Threaded Type Body	316 sst, Hastelloy C[1] alloy
Orifice Plate	316 sst, Hastelloy C alloy
Flanged Type	All 316 sst only
Sealing Gasket	Silicate ceramic filled TFE

Concentric Orifice Bores

1 in.	0.020, 0.035, 0.065, 0.113, 0.195, 0.340, 0.500, 0.735 in.
1½ in.	0.500, 0.612, 0.750, 0.918, 1.127 in.
Pipe Size	1 in. and 1 ½ in.
Pipe Schedule	Schedule 40
Connection to Transmitter	Flat gasketed surfaces bolted to transmitter or 3-valve manifold

Face-to-Face Dimensi

Threaded Type	1 in. NPT 3 11/16 in (93.7 mm) 1 ½ in. NPT 4 1/16 in. (103.2 mm)
Flanged Type	24 in. (610 mm) 38 in. (965 mm)
NACE Standard	Construction materials Type 316 sst with Type 316 sst Orifice Plate and Type 316 sst with Hastelloy C alloy Orifice Plate conform to NACE Standard MR-01-75. Conformance is on process-wetted materials only; does not include bolting.

DETERMINATION OF ORIFICE BORE AND DIFFERENTIAL PRESSURE

ORIFICE BORE

To determine the bore for a particular application, use the following procedure:

1. Multiply a given maximum flow rate by appropriate correction factor shown below:

   Liquid (U.S. gpm): Correction Factor = 1

   Gas (scfh): *Correction Factor* = $\frac{0.22 \times T}{P}$

   Steam (lb/hr): Correction Factor = $0.2576 \times \overline{V}$

   Where: P = process pressure in psia (psig + 14.7)
   T = process temperature in °R (°F + 460)
   $\overline{V}$ = specific volume of steam (cu ft/lb)

2. Match this corrected flow rate to values shown in Capacity Tables to determine bore required to produce a desired differential pressure.

   Example: 1000 scfh of CO_2 gas at 50 psig and 90°F in a 1 in. line. We want to pick orifice bore to produce 50 in. of H_2O.

   $$1000 \times \left[\frac{0.22 \times (90 + 460)}{(50 + 14.7)}\right] = 1870 \text{ scfh}$$

   From Capacity Table, a 1 in. integral orifice having a bore of 0.340 will produce 50 in. of differential at 1786 scfh. We would select a 0.340 bore.

DIFFERENTIAL PRESSURE

To determine the differential pressure for a particular application, use the following procedure:

1. To correct a value for differential pressure read directly from Capacity Tables for actual flowing conditions, use the following:

   Liquid: $h = h \text{ (from chart)} \times g_f$

   Gas: $h = h \text{ (from chart)} \times \left[\frac{G \times T \times 0.22}{P}\right]$

   Steam: $h = h \text{ (from chart)} \times \overline{V} \times 0.2576$

2. To calculate exact differential pressure produced at known flow rate, use one of following equations:

   Liquid: $h = g_f \left[\frac{q \text{ (in U.S. gpm)}}{5.663 \times F_a \times K \times d^2}\right]^2$

   Gas: $h = \frac{GT}{P}\left[\frac{Q \text{ (in scfh)}}{7727 \times F_a \times K \times d^2 \times Y}\right]^2$

   Steam: $h = \overline{V}\left[\frac{W \text{ (lb/hr)}}{359 \times F_a \times K \times d^2 \times Y}\right]^2$

[1]Trademark of Union Carbide Corporation

Where: d = bore diameter in in.
F_a = orifice expansion factor
G = specific gravity of gas
g_f = specific gravity of liquid at flow conditions
h = differential pressure in in. H_2O
K = flow coefficient
P = process temperature in psia (psig + 14.7)
Q = flow rate of gas
q = flow rate of liquid
T = process temperature in °R (°F + 460)
$\overline{V}$ = specific volume of steam in cu ft/lb
W = flow rate of steam
Y = correction factor

Example: *Continuing the preceding example, having selected a bore diameter (d) of 0.340 in , we find, from charts on next page, that:*
β = 0.30
F_a = 1.0002
K = 0.605
Y = 0.9917

Therefore:
$$h = \frac{1.517 \times 550}{64.7} \times \left[\frac{1000}{7727 \times 1.0002 \times 0.605 \times 0.340^2 \times 0.9917}\right]^2$$

h = 44.88 in. H_2O

CAPACITY TABLE – 1"

Orifice Bore (Inches)	Differential Pressure (Inches H_2O)	Liquid[1] Flow Rate gpm	Gas[2] Flow Rate scfh	Saturated Steam[3] Flow Rate lbs/hr
	200	.021	13.2	
	100	.015	9.3	
.020	50	.010	6.6	–
	20	.006	4.2	
	10	.005	2.95	
	200	.062	39.7	
	100	.044	28.1	
.035	50	.031	19.9	–
	20	.020	12.6	
	10	.014	8.9	
	200	.210	134	
	100	.148	95	
.065	50	.105	67	–
	20	.066	42	
	10	.047	30	
	200	.618	394	19.2
	100	.438	279	13.7
.113	50	.310	197	9.9
	20	.195	125	6.1
	10	.137	88	4.3
	200	1.850	1183	57.8
	100	1.317	836	41.4
.196	50	.933	591	29.5
	20	.588	374	18.4
	10	.417	264	13.1
	200	5.600	3572	175
	100	3.967	2525	122
.340	50	2.800	1786	88.6
	20	1.767	1129	55.3
	10	1.250	798	39.4
	200	12.617	8043	398
	100	8.917	5687	284
.500	50	6.300	4022	201
	20	3.983	2543	127
	10	2.817	1798	85.8
	200	30.93	19700	973
	100	21.88	13950	693
.735	50	15.47	9860	493
	20	9.78	6240	312
	10	6.92	4410	220

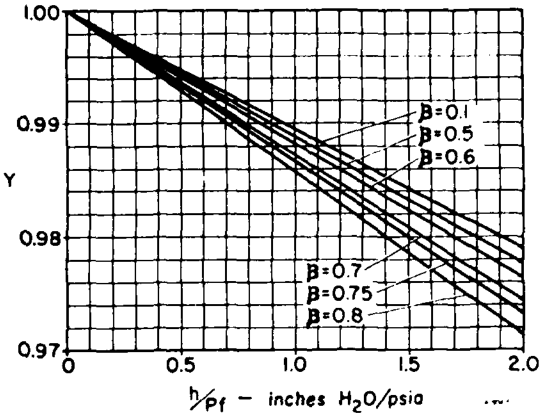
1. Based on water flow.
2. Based on air flow at 100 psig and 60°F.
3. Based on steam flow at 100 psig.

CAPACITY TABLE – 1-1/2"

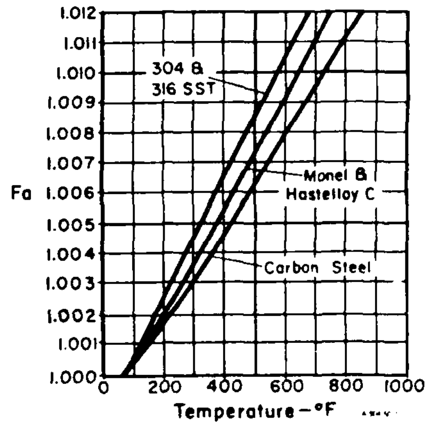
Orifice Bore (Inches)	Differential Pressure (Inches H_2O)	Liquid[1] Flow Rate gpm	Gas[2] Flow Rate scfh	Saturated Steam[3] Flow Rate lbs/hr
	200	12.2	7801	390
	100	8.6	5516	276
0.500	50	6.1	3900	195
	20	3.8	2467	123
	10	2.7	1744	87
	200	18.4	11783	589
	100	13.0	8332	417
0.612	50	9.2	5892	295
	20	5.8	3726	186
	10	4.1	2635	132
	200	28.1	17985	900
	100	19.8	12718	636
0.750	50	14.0	8993	450
	20	8.9	5688	284
	10	6.3	4022	201
	200	43.9	28156	1408
	100	31.1	19910	996
0.918	50	22.0	14078	704
	20	13.9	8904	445
	10	9.8	6296	315
	200	72.6	46542	2327
	100	51.4	32911	1646
1.127	50	36.3	23272	1164
	20	23.0	14718	736
	10	16.2	10407	520

1. Based on water flow
2. Based on air flow at 100 psig and 60°F.
3. Based on steam flow at 100 psig

Pipe Size	Orifice Bore Inches	Nominal Flow Coefficient K
1-inch	0.020	0.645
	0.035	0.635
	0.065	0.620
	0.113	0.605
	0.196	0.603
	0.340	0.605
	0.500	0.630
	0.735	0.715
1-1/2 inch	0.500	0.611
	0.612	0.614
	0.750	0.623
	0.917	0.650
	1.127	0.714



Pipe Size Inches	Orifice Dia. Inches	β
1	0.02	0.1
1	0.035	0.1
1	0.065	0.1
1	0.113	0.1
1	0.196	0.2
1	0.34	0.3
1	0.5	0.5
1	0.735	0.7
1-1/2	0.5	0.3
1-1/2	0.612	0.4
1-1/2	0.750	0.5
1-1/2	0.918	0.6
1-1/2	1.127	0.7



Orifice Expansion Factor

INTEGRAL ORIFICE FLOW
1 in. and 1½ in. NPT SIZES

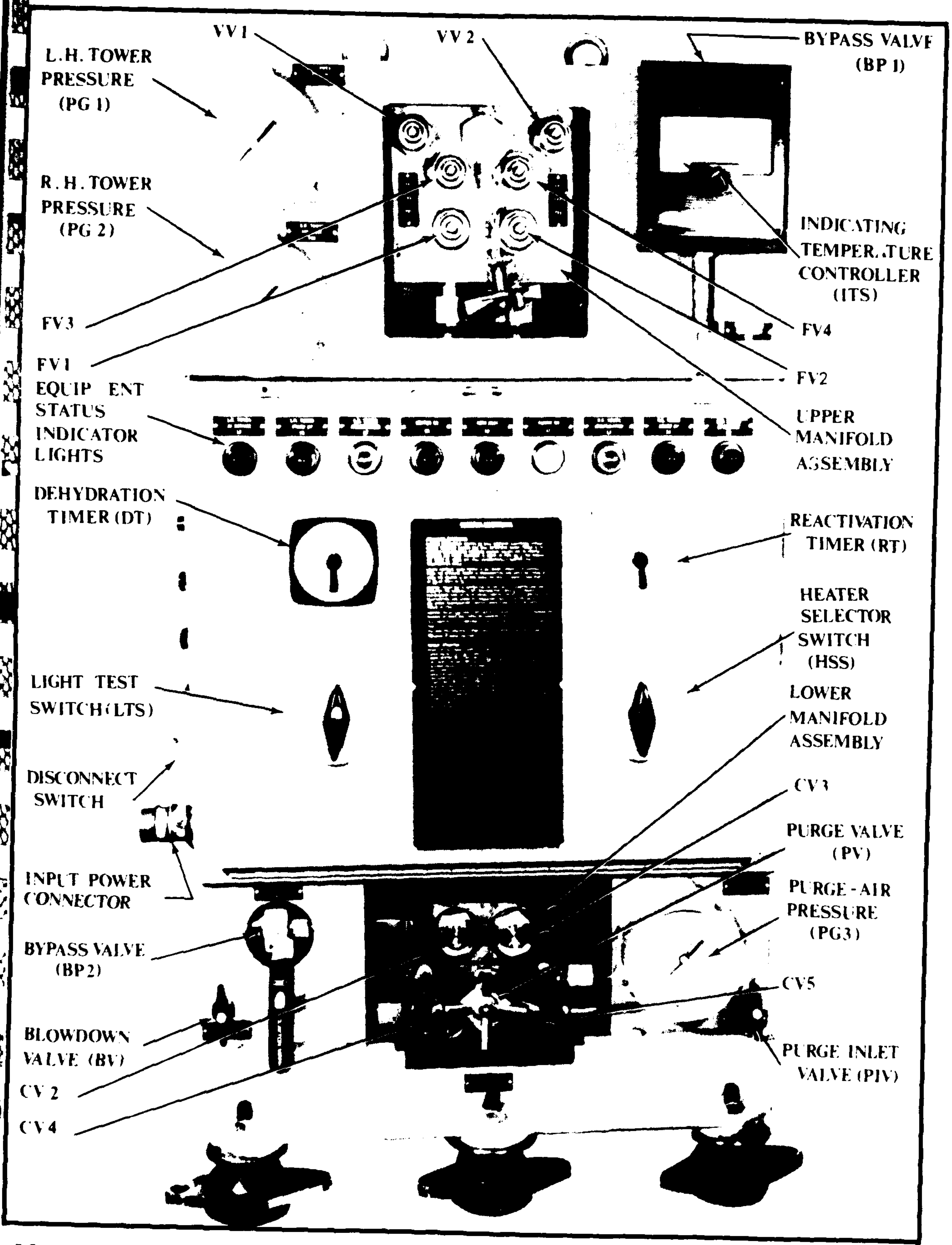


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Figure C-8 *Model 10101-7 Operating Controls.*

TABLE 3

AIR DRY HPAD REFERENCE DATA

Service	Air
Operation	Semi-Automatic
Duty	Continuous
Electrical Requirements	Single Phase, 440 volts, 60 Hz, 2.7 KVA
Ambient Air Conditions	60 to 130°F
Inlet Air Conditions:	
Flow (Rated)	150 SCFM
Temperature	105°F
Water Content	Saturated
Oil Content	1.0 ppm by Wt. Max.
Outlet Air Conditions:	
Pressure*	**3400-4500 PSI**
Flow (Net with Internal Purge Air Supply)	135 SCFM
Temperature	115°F (maximum)
Water Content	−60°F Dew Point at 4500 PSI
Oil Content	0.1 ppm by Wt. (maximum)
Pressure Drop (Exclusive of Back Pressure Valve Action)	80 PSI
Purge-Air:	
Flow	**15 SCFM at 50 PSI at the Exhaust Orifice**
External Supply	**125 PSI** (Moisture content 0.000015 lb. H_2O/lb. air max.)
Reactivation Time: (4 hours)	
Heating	3 Hours
Cool Down	1 Hour
Heater Element:	
Capacity	2400 Watts
Resistance	80±5 OHMS
Port Connections:	
Air Inlet and Outlet	½ in. IPS Union Ends per BUSHIPS Dwg. No. 810-1385884
Blow Down	¼ in. MS16142
External Purge Air Inlet	⅜ in. MS16142
Bypass System:	
Inlet Air Pressure (Design)	**4600 PSI**
Inlet Air Temperature	105°F
Inlet Air Moisture Content	Saturated
Inlet Air Oil Content	1.0 ppm by Wt.
Flow	132.5 SCFM
Outlet Air Pressure	**Inlet Pressure - Approximately 50 PSI**
Outlet Air Temperature	110°F (maximum)
Outlet Air Moisture Content	−60°F Dew Point at 4500 PSI (maximum)
Overall Dimensions:	
Height	42 inches
Width	24 inches
Depth	20 inches
Recommended Clearance for Maintenance:	
Front	27 inches (minimum)
Top	18 inches (minimum)
Sides and Back	12 inches (minimum)
Weight:	975 lbs.
Dehydration Time (DT):	

$$\textit{Main System DT} = 4\left(\frac{\textit{Rated Capacity (150 SCFM)}}{\textit{Actual Flow (SCFM)}^{**}}\right)$$

$$\textit{Bypass System DT} = 4\left(\frac{\textit{Rated Capacity (132.5 SCFM)}}{\textit{Actual Flow (SCFM)}^{**}}\right)$$

*After Ship Air Banks are changed

(**Actual Flow = Air Compressor Rating (57.6 SCFM) times number of compressors operating)

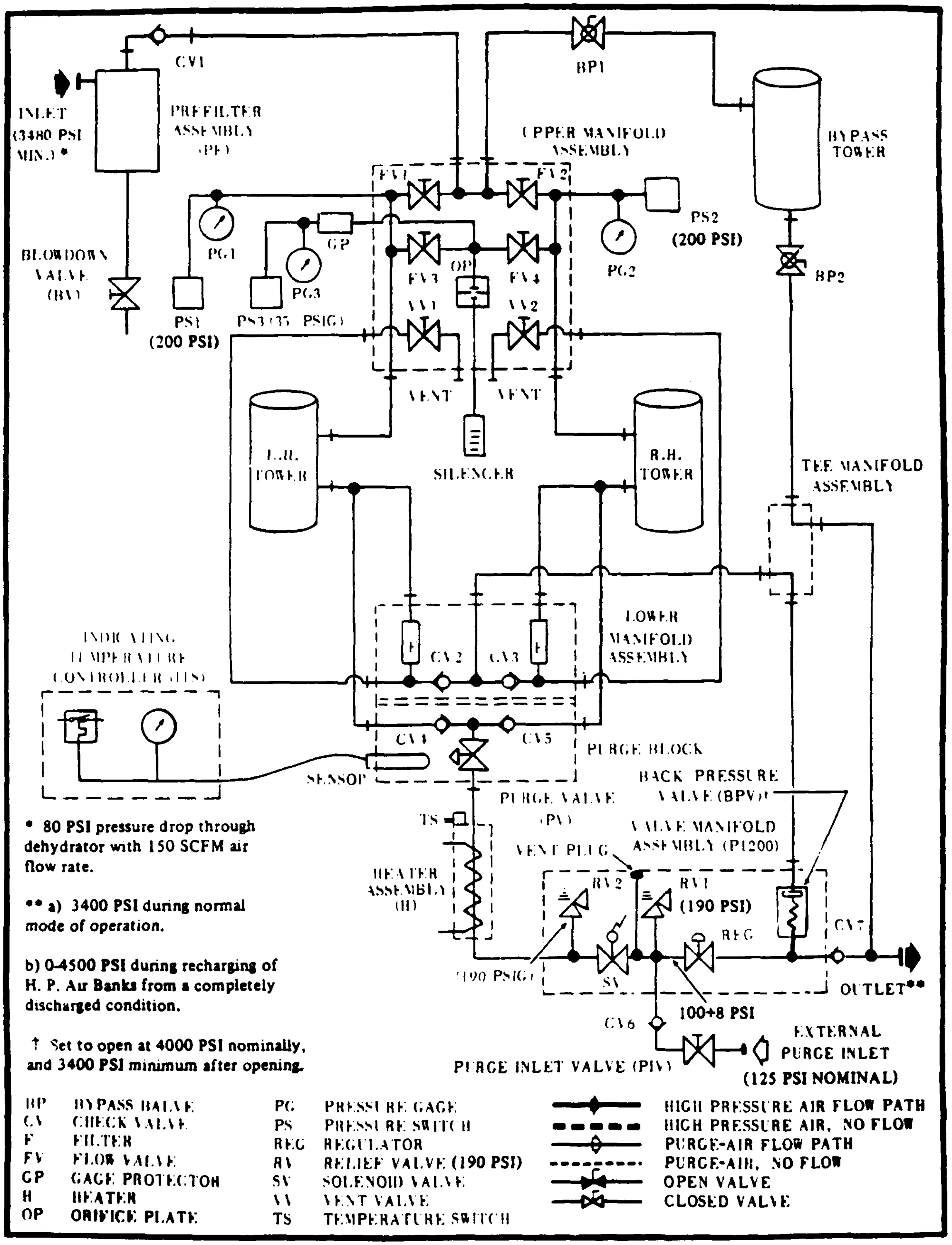


Figure C-9
AIR DRY HPAD FLOW DIAGRAM

PRODUCT DATA

H-152

CHE 944

Alcoa Chemicals Division

Activated Adsorbent For Dehydration Applications

April 1985

Product Information

Alcoa H-152 is a smooth, spherical, enhanced activated alumina with properties uniquely designed to optimize desiccant performance. H-152 was developed to replace Alcoa H-151 in dehydration applications with the added benefits of higher sorptive capacities at low and high relative humidities.

Alcoa H-152 is available as 1/8" *and* 3/16" spheres. Other sizes can be produced *subject to special inquiry.*

Product Applications

In comparison with H-151 and other commercially available alumina desiccants, H-152 yields comparable or lower dewpoints and higher overall dehydration capacity. Because of the unique manufacturing process, H-152 has significantly higher strength and lower abrasion loss allowing pneumatic or other loading methods.

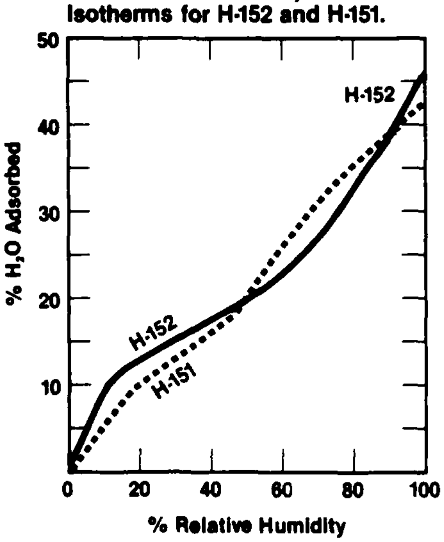
H-152 can be used as a premium desiccant in most gas and liquid systems. For information regarding your particular application, please contact:

Alcoa Adsorption Center - Houston Sales
Phone (713) 999-6050

-or-

Alcoa Technical Service - Pittsburgh
Phone (412) 553-2176

Ambient Water Adsorption Isotherms for H-152 and H-151.



TYPICAL PHYSICAL PROPERTIES		H-151 1/8" *(No longer produced)*	H-152 1/8"	H-152 3/16"
Static Adsorption (wt%)	@ 11% RH	6	12	11
	@ 58% RH	24	22	21
	@ 97% RH	42	43	42
Abrasion Loss (wt%)		0.3	0.1	0.1
Crush (lbs)		15	30	55
Bulk Density (lbs/ft^3)		53	48	48
TYPICAL CHEMICAL PROPERTIES (WT%)				
Al_2O_3		90.2	80.6	80.6
SiO_2		2.1	9.9	9.9
Na_2O		1.6	5.4	5.4
Fe_2O_3		0.03	0.03	0.03
LOI (250 - 1200° C)		6.0	4.0	4.0

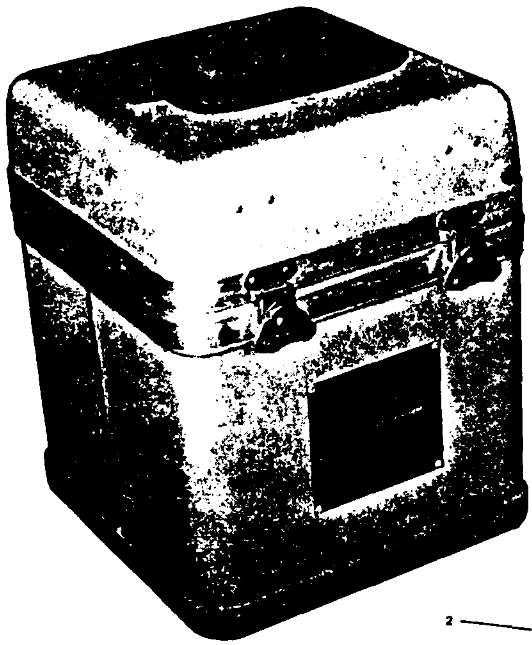
For product samples and information on availability and price of H-152 activated alumina, please contact your nearest Alcoa sales office. The Chemical Sales Unit at (800) 643-8771 can also answer your inquiry.

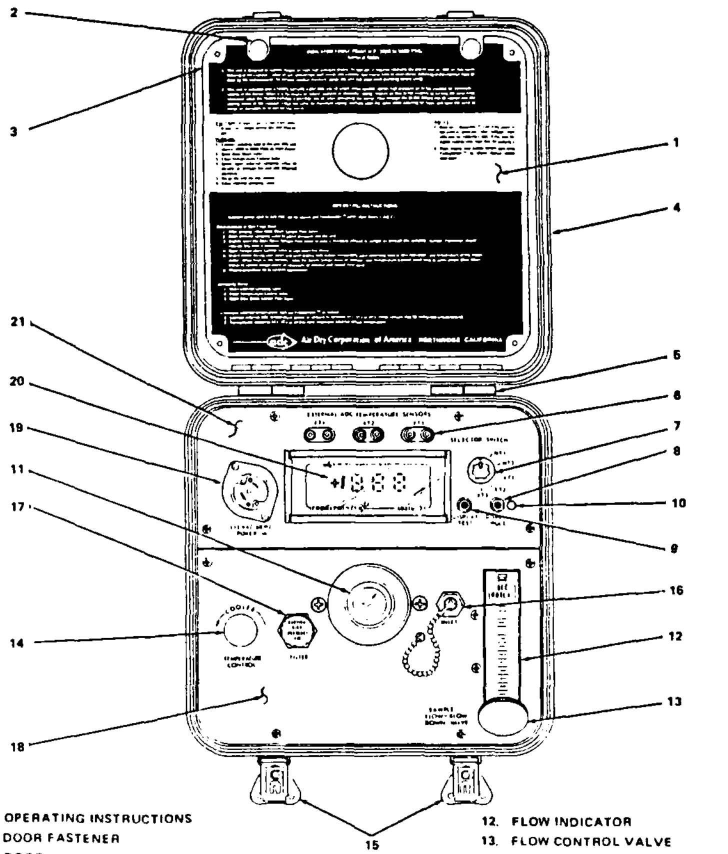
Information presented herein is believed to be accurate and reliable but does not imply any guarantee or warranty by Alcoa®. Nothing herein shall be construed as an invitation to use processes covered by patents without proper arrangements with individuals or companies owning those patents.

Aluminum Company of America
1501 Alcoa Building   Chemicals Division   Pittsburgh, PA 15219

ALCOA

Form No. F35-14662





1. OPERATING INSTRUCTIONS
2. DOOR FASTENER
3. DOOR
4. LID
5. OFFSET HINGES
6. TERMINALS FOR EXTERNAL PROBES
7. SELECTOR SWITCH
8. DISPLAY HOLD PUSHBUTTON SWITCH
9. DISPLAY TEST PUSHBUTTON SWITCH
10. DISPLAY HOLD LIGHT
11. MIRROR MAGNIFIER
12. FLOW INDICATOR
13. FLOW CONTROL VALVE
14. TEMPERATURE CONTROL VALV
15. CASE LATCHES
16. SAMPLE GAS INLET
17. FILTER
18. PNEUMATIC PANEL
19. SOCKET FOR POWER CORD
20. DIGITAL METER
21. ELECTRICAL PANEL

Figure C-10
AIR DRY DEWPOINT INDICATOR
MODEL 10310-24

TABLE 4

AIR DRY DEWPOINT INDICATOR REFERENCE DATA

Service	gas
Operation	manual
Duty	continuous
Maximum Operating Pressure:	
Sample Gas	5,000 psig maximum
Flow Rate:	
Coolant Gas	1.5 SCFM at 3,000 psig
Sample Gas	1 to 3 SCFH
Performance:	
Range of Frost Point Indication	-70°F (-56.7° C) to +0°F (-17.8°C)
Frost Point Accuracy	±5°F (±2.78°C) temperature range
Cooling Rate at 3,000 psig inlet min (Sample flow set at "4" on flow indicator)	-60°F (-51.1°C) within 5 minutes, starting at 70°F (21.1°C)
Operating Pressure Range:	
Sample Gas	3,000 to 5,000 psig
Sample Flow, preferred setting for operation	set float ball at "4" on the indicator to determine frost-point
Gas consumption – Cooling Module	1.5 SCFM at 3,000 psig inlet (±10%)
Electrical Requirements	115 vac 60 Hz
Port Connections	O-Ring face seal (¼ inch O.D. tube size)
Overall Dimensions:	
Height	13.5 inches
Depth	11.5 inches
Width	10.6 inches
Weight	15 lbs
Operation Limitations	+40°F (4.44°C) to 130°F (54°C) ambient
Storage	-60°F (-51.1°C) to +180°F (82°C) ambient

SPECIFICATIONS

PNEUMETRICS MODEL MARK 1

A. ELECTRONICS SECTION

Display:	LED, 0.4", 4 digit
Sample Rate:	$\geq$ 2.5 samples per second
Operating Temperature:	$0^{o}C$ to $55^{o}C$
Storage Temperature:	$-40^{o}C$ to $+85^{o}C$
Supply Voltage:	115 VAC or 220 VAC, 50/60 Hz, $\pm$10%
Sensor Input:	Single moisture sensor. Sensor cable connects at the rear of the unit via #6 screw terminals.
Physical Characteristics:	Standard 1/4 DIN case, panel mount, weighing approximately 2.5 lbs. Weatherproof and explosion proof cases are available on special order.

B. SENSOR

Calibration:	Factory calibrated. Data stored in internal plug-in EPROM.
Measurement Range:	Varies per application. Typical ranges: $-80^{o}F$ to $+20^{o}F$, $0^{o}F$ to $+50^{o}F$, 0-1000 PPMv
Operating Temperatures:	$-110^{o}C$ to $+70^{o}C$
Operating Pressure:	To 5000 psig

All specifications are subject to change without notice.

Instrument Manual

5700
Moisture Analyzer

E. I. du Pont de Nemours & Co.
Instrument Systems
Concord Plaza — Quillen Building
Wilmington, DE 19898

P/N 571002-901, Rev B
May 1985

PART 1

GETTING TO KNOW THE ANALYZER

Purpose of the Analyzer

The moisture analyzer is a microprocessor controlled instrument that measures trace concentrations of water in laboratory gases such as air, oxygen, and nitrogen at parts per million by volume (ppmv). It has a 0 to 5-V dc analog output capable of driving a 2000-ohm load.

Description of the System

The moisture analyzer (figure 1-1) consists of a dryer and an analyzer. The unit can be used only in a general purpose area. A rack-mounted accessory is optional.

Dryer

A dryer filled with Linde molecular sieve or another suitable desiccant is recommended to dry the reference gas to less than 0.1 part per million by volume.

Analyzer (figure 1-2)

This unit contains all components necessary to control gas flow, determine moisture content, process and display moisture level values, and calibrate the instrument. Optional accessories provide an RS-232-C serial interface.

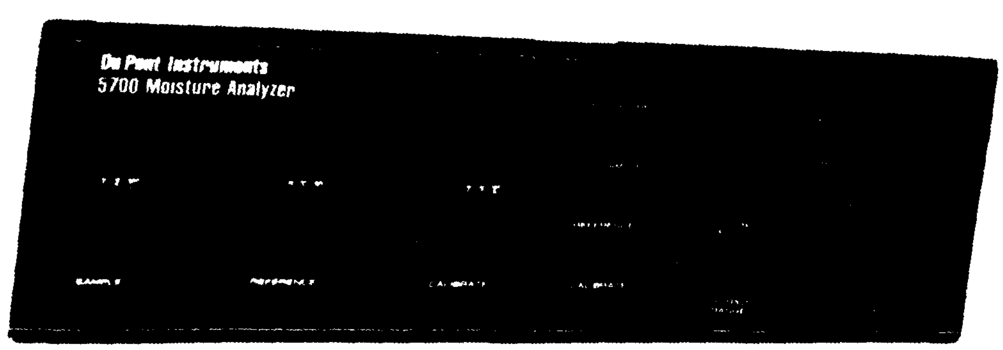
Major components include front panel controls and indicators, rear panel connectors, a sample system oven, a power transformer, cell, and a main analog input pc board.

• Front Panel

These controls provide calibration standard switching, output range selection, and gas flow control. Indicators relate sample system and oven temperature status and sample moisture content in ppm v/v. Moisture cell and wet/dry frequencies also are displayed when so programmed by internal switches.

• Rear Panel

Terminals provide connections for the analog output, and for high, low, and fault alarms. A fuse



cycling and electromagnetic interference. The control also signals the microprocessor so it can determine if temperature is in control.

- High resolution frequency counter. This reads the frequency outputs from the sample cell crystals every second.
- Timer. This provides 256-per-second interrupts to the microprocessor to control valve switching and to operate the counter.
- Dc power supply. This provides +5 and ± 12-volt regulated and +24-volt unregulated outputs.
- Microcomputer. This includes an Intel 8085 microprocessor, an EPROM, RAMs, an EEPROM, an address latch, and two address decoders.
- Test switch. This 16-position rotary switch provides test, service, and diagnostic capabilities.
- Data input switches. Four 10-position rotary switches enable changing of EEPROM-stored variables.
- Alarm relays. Two range relays provide normally-open and normally-closed contacts which are triggered when the ppm level is above or below the setpoint levels. A third relay signals faults within the analyzer.
- Solenoid valve drivers. This IC switches +24 volts to operate sample system solenoid valves and the alarm relays.
- D/A converter. This converts the computer output to the analog signal required for external recording.

How the Sample System Operates

Terms

- **Cell Frequency** — The frequency of the square wave produced by the cell pc board.
- **Wet Frequency** — The cell frequency during the last second of the 30-second sample cycle.
- **Dry Frequency** — The cell frequency during the last second of the 30-second reference cycle. It always is less than the wet frequency.
- **Delta Frequency** — The difference between the wet and the dry frequencies (wet - dry). Delta frequency is used as the argument of the polynomial used to calculate ppm from frequency.
- **Clock Frequency** — A 2-MHz square wave, generated by the microprocessor, used for time-base measurements.
- **Span** — A user-entered variable related to moisture. This is determined during factory calibration and may vary during the cell lifetime. New span values may be user-determined if known moisture standards which can be used with the 5700 are available, such as the internal moisture generator.

Functional (figure 1-3)

The moisture analyzer compares the frequency of two crystal-controlled oscillators (Y_1 and Y_2). One crystal (Y_2) is coated with a thin film of hygroscopic material and placed in an enclosed cell. This crystal is the measuring crystal, with a nominal operating frequency of 9 MHz. The second crystal (Y_1) is the local oscillator crystal (LOC), with a nominal operating frequency of 9.0005 MHz. Sample and reference gas flow through the measuring crystal cell is alternated every 30 seconds by solenoid valves L1 and L2. These valves are switched by a valve switching signal from the microprocessor. With valve L1 energized, sample gas flows through the crystal cell. During this cycle, the hygroscopic material on the measuring crystal sorbs moisture from the sample gas. This sorbed moisture increases the mass of the crystal, causing the crystal frequency to decrease. The local oscillator frequency (F_1) is continuously mixed with the measuring frequency (F_2) to produce a cell frequency signal, which is then amplified, shaped into a square wave, and sent to the microprocessor.

Since the LOC oscillates at a frequency higher than the measuring crystal, when F_2 drops because of increasing moisture, the difference between them increases.

The microprocessor enables triple counter U10 at the beginning of each second and disables it at the end of each second. J-K flip-flop U11 syncronizes counting to negative transitions of the cell

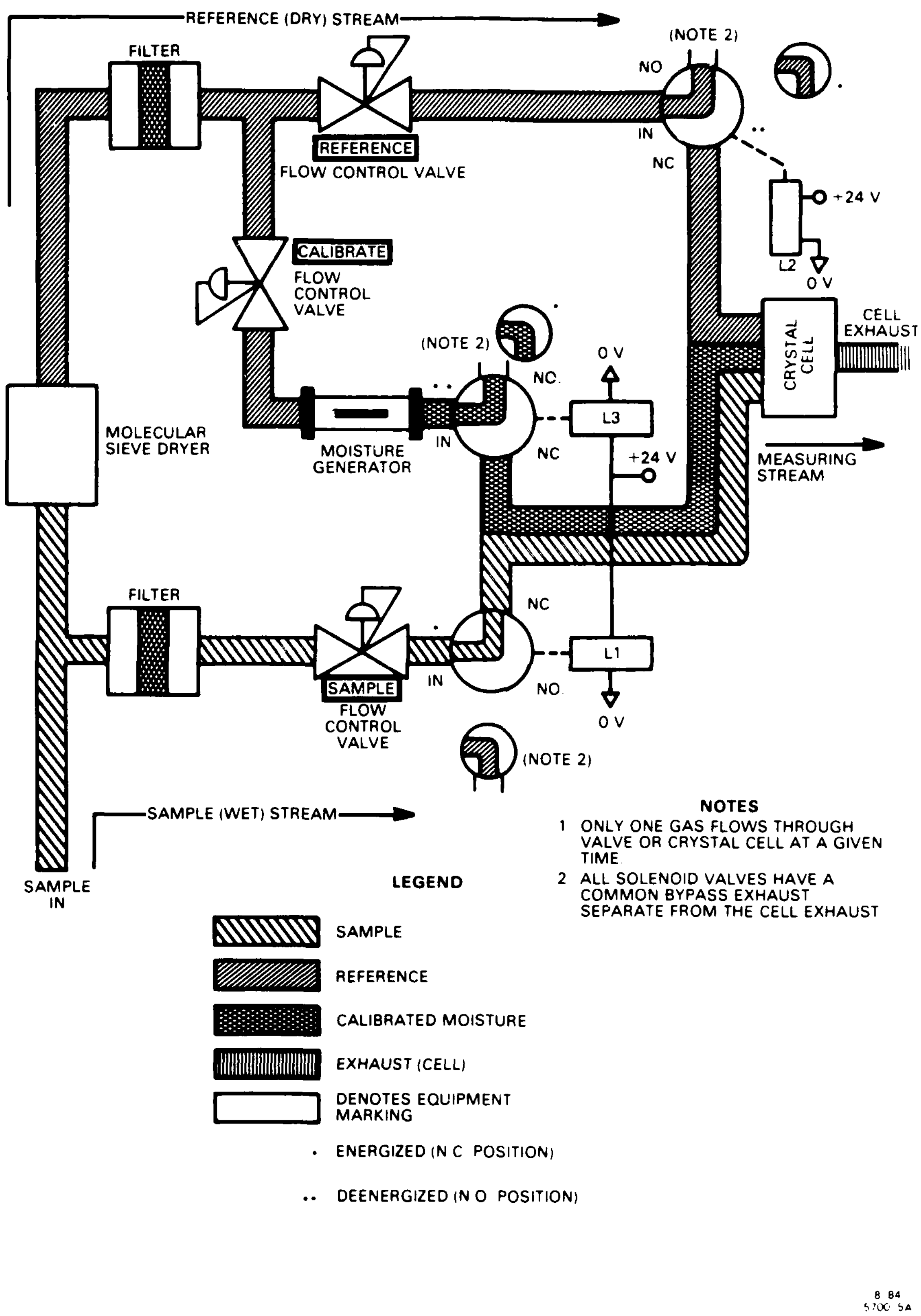


Figure C-11 Gas Flow Diagram for Dupoint 5700 Moisture Analyzer

High Resolution Frequency Counter

The input frequency is measured by a microprocessor controlled frequency counter capable of reading the frequency to a resolution of ±0.00006 percent and taking a reading every second.

Display

From the microprocessor, the value to be displayed is transmitted to a display driver which reads and stores the value, and drives four LEDs which indicate which valve is enabled and if the oven is up to operating temperature.

Analog Output

The 0 to 5-volt dc analog output is linear with moisture and capable of driving a 2000-ohm load. The signal is developed by U3, U4, and U5. U3 is a microprocessor compatible, 12-bit, digital-to-analog (D/A) converter. It generates two complementary currents proportional to the digital number loaded into it. Op-amp U4 converts the two currents to the 0 to 5-volt output. R8, a 25-kilohm trimmer, adjusts the offset of U4 and thus the analog output zero. U5, together with R4, R5, and R6, produces the -5.00-volt reference for U3. R4, a 1-kilohm trimmer, adjusts the reference voltage and thus analog output span.

Temperature Control

The temperature controller maintains the oven at a nominal 60° C. The controller uses time proportioning and zero crossover ac switching to reduce temperature cycling and generated electromagnetic interference (emi). The controller also provides a signal to the microprocessor, which allows it to determine when oven temperature is at the control point.

Temperature is sensed by a thermistor, mounted on the board socket which connects the moisture/frequency transducer board. With the thermistor close to the transducer, the most critical components are accurately maintained at the proper temperature. The thermistor, together with R9 and R10, forms a voltage divider whose output is 0 volt when temperature is correct.

LED CR1 is on when power is applied to the oven heater; it flashes when the temperature is at the setpoint. Relay K4 turns the heater on and off at the ac zero crossover point and thus reduces emi.

Miscellaneous

Range switch S1 selects one of four analog output ranges. Changing the range affects only the analog output, not the display moisture value. Resistors protect the inputs and provide a default range if the front panel board is disconnected.

CAL switch S2 enables the internal calibration standard. With S2 on, moisture from the calibration standard flows to the cell instead of sample.

TEST switch S1 on the microprocessor board provides 16 positions for tests, service aids, and diagnostics.

Data entry switches S2, S3, S4, and S5 are four BCD switches which, along with the TEST switch, change the variables stored in EEPROM U22 (non-volatile parameter memory).

DC Power Supply

Five volts are produced by full wave rectifying the 14-volt, center-tapped winding of power transformer T1 using CR4 and CR5. The rectified voltage is filtered by capacitor C21 and regulated by three-terminal regulator VR1.

Plus and minus 12 volts are produced by full-wave rectifying the 26-volt, center-tapped winding of T1 using CR6, CR7, CR8, and CR9. The positive voltage is filtered by C30 and regulated by VR2. The minus voltage is filtered by C25 and regulated by VR3.

Unregulated 24 volts is produced by full wave rectifying the 30-volt, center-tapped winding of T1 using CR2 and CR3. It is filtered by C20.

Specifications

- **Ranges:** Operating range 0 to 1000 ppm (calibrated 0 to 100 ppm). Display provides trend indication above the calibrated range. Selectable range segments of 0 to 1, 10, 100, and 1000 ppm are provided
- **Outputs:**
  - **Instrument**
    - Six, 7-segment digital display
    - 0 to 5-V isolated analog output into a 2000-ohm minimum load
  - **Alarms**
    - Two user-settable NO or NC contacts for moisture levels
    - Possible software or hardware fault
- **Sensitivity:** ±2% of range segment for 0 to 100 ppm
- **Response Time:** 63 percent to a step change in less than 5 minutes
- **Accuracy:** ±0.1 ppm or ±5% of the reading, whichever is greater

• **Electrical Accuracy:**	±0.01% of moisture cell output
• **Operating Pressure:**	0.5 to 7 bars gauge (7.5 to 100 psig)
• **Exhaust Pressure:**	Atmospheric [0.1 bar gauge (2 psig) max]
• **Gas Flow Requirements:**	200 mL/min at standard temperature and pressure (760 mm Hg at 25° C) for each of the three flows
• **Power Requirements:**	100 ±8 V, 50 to 60 Hz 115 ±10 V, 50 to 60 Hz 220 ±20 V, 50 to 60 Hz 240 ±20 V, 50 to 60 Hz 200 W
• **Gas Temperature**	0° C to 100° C
• **Electrical Classification:**	Division II
• **Ambient Temperature Limits (still air):**	4° to 52° C (40° to 125° F) 90% relative humidity, non-condensing, non-corrosive
• **Alarm Contact Rating:**	115 V ac or 30 V dc, 2 A, 60 W or 100 VA
• **Oven Temperature:**	60° C ±0.2° C
• **Size:**	43.2 × 13.2 × 38.1 cm (17 x 5.2 × 15 in.)
• **Net Weight:**	17 kg (37 lb)

KAHN

Instruction Manual

THE KAHN COMPANIES
885 Wells Road, Wethersfield, CT 06109 Phone (203) 529-8643 Telex 9-9301 Fax (203) 529-1895

KAHN

SOME DISTINGUISHING FEATURES OF THE KAHN MD10 DEWPOINTMETER

- RUGGED AND PORTABLE. DESIGNED FOR HARD FIELD USE.
- HEAVY DUTY CARRYING CASE.
- HIGH ACCURACY (+/- 2 °C)
- WIDE RANGE (-100°C TO +30°C).
- CALIBRATION TRACEABLE TO NATIONAL BUREAU OF STANDARDS.
- RAPID RESPONSE (90% OF MOST STEP CHANGES IN SECONDS)
- MICROPROCESSOR CONTROLLED:
  - AUTOMATIC, ELECTRONICALLY PROGRAMMED CALIBRATION OCCURS EACH TIME THE INSTRUMENT IS TURNED ON.
  - EXTREMELY LOW CURRENT CONSUMPTION.
  - USER SELECTABLE UNITS (°C, °F, PPMV for all gases and PPMW for air, nitrogen, hydrogen or natural gas).
- VERY LOW SAMPLE FLOW REQUIREMENTS (0.25 L/MIN IS AMPLE)
- "SYSTEM PURGE" FEATURE FOR ACCELERATED RESPONSE AT VERY LOW DEWPOINTS.
- OPERATES OFF RECHARGEABLE NI-CAD BATTERY OR LINE CURRENT.
- GAS SAMPLE TEMPERATURE INDICATION.
- RECORDER OUTPUT WITH ADJUSTABLE ZERO AND RANGE.
- DIGITAL LIQUID CRYSTAL AND ANALOG BAR DISPLAYS.

Figure C-12 Kahn MD10 Dewpointmeter

9.0 CALIBRATION AND TRACEABILITY

The MD10 is supplied fully calibrated over the range -80 to +30 degrees C dewpoint. Calibrations are traceable to the National Bureau of Standards. The Calibration Certificate supplied with the instrument specifies the calibration gas dewpoints used and states the calibration accuracy over the range.

The Calibration EPROM stores information on the month and year of calibration, sensor number, batch number, and other software reference information. To obtain this information select position 9 on the UNITS SELECTOR (see Section 4.0). Successive depression of the CAL. TEST button on the front panel will display this information along with a reference on the bar display:

1 bar	Month and Year
2 bars	Sensor Number
3 bars	Batch Number
4 bars	Software reference data

10.0 WARRANTY

All hygrometers and sensors are warranted for construction and calibration for one year, excluding damage or misuse.

11.0 SPECIFICATIONS

Dimensions (inches):
  Without carrying case: 8.5 W x 3.5 H x 10.5 D
  With carrying case: 10 W x 5 H x 11.5 D

Weight (lbs):
  Instrument: 11-1/2 lbs.
  Carrying Case: 3-1/2 lbs.

Materials of construction:
  Instrument case: steel.
  Finish: Cadmium plated, passivated, matte black stove enamel.

Sensor:
  Kahn Thin-Film Aluminum-Oxide, very high capacitance type. Mounting in stainless steel or aluminum body. Integral EPROM lineariser.

11.0 SPECIFICATIONS (Continued)

Sampling system:
Standard Model: Stainless Steel sensor housing.
PTFE (Teflon) sample tubing.

Resolution and Accuracy:
+30 to -40 degrees C dewpoint: +/-2 degrees C dewpoint.
-40 to -80 degrees C dewpoints: +/-3 degrees C dewpoint.

Calibration:
Ten point calibration by systems traceable to the National Bureau of Standards.

Response Time:
Reads 90% of step change in 5 seconds (minimum) to 3 minutes (maximum) with System Purge.

Outputs:
0-10 millivolt, linear output. Adjustable zero and range.

Display:
LCD digital and analog bar display.
Customer selectable units:
dewpoint in °C or °F,
ppm(V),
ppm(W) for Air, Hydrogen, Nitrogen, Carbon Dioxide and Natural Gas.

Sample gas conditions: (Not critical for accuracy)
Inlet pressure: 0 - 5000 psig (standard models)
0 - 15 psig (models with System Purge option)
Flow rate: 0.25 - 15.0 liters/minute (0.5 - 30 scfh)

Temperatures:
Storage : -50 to +70°C
Operating : -10 to +40°C. Temperature must always be higher than measured dewpoint to avoid condensation.

Kahn Instruments
885 Wells Road
Wethersfield, CT 06109

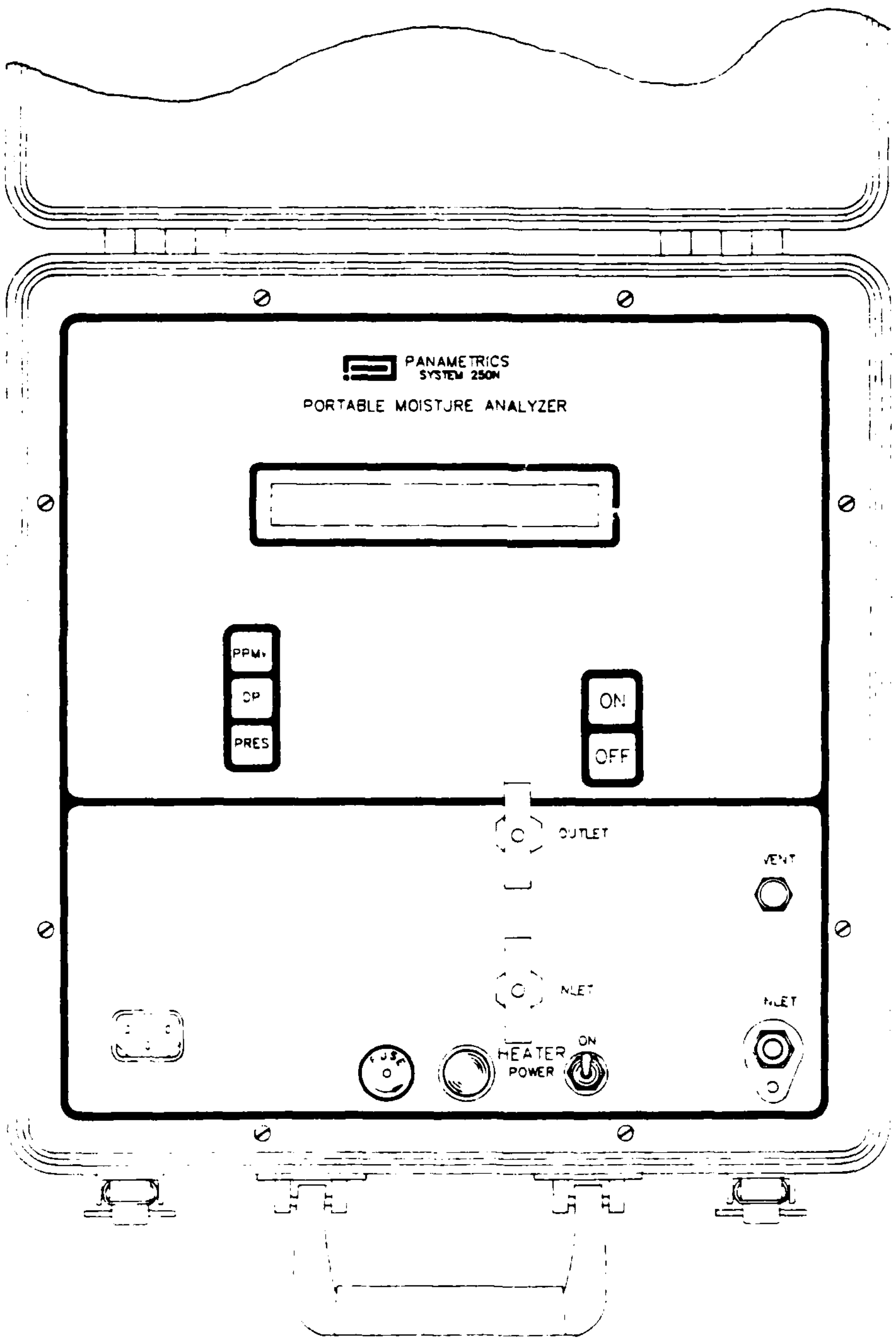
Telephone: (203) 529-8643
Telex: 99301
Facsimile: (203) 529-1895

MODEL 250N

PORTABLE MOISTURE ANALYZER

PANAMETRICS

Panametrics Inc. 221 Crescent Street, Waltham, MA 02254 / 617 899-2719 Telex 951006



The System 250N

Figure C-13 Panametrics 250N Moisture Analyzer

SECTION 1

1.1 INTRODUCTION

This manual contains instructions for calibration, operation, and maintenance of the Panametrics System 250N Portable Moisture Analyzer. The System 250N is a complete test package for checking moisture concentrations in shipboard high pressure air storage banks. The compact unit is designed for on-the-spot moisture measurements on board submarines, but can be utilized in any similar applications.

1.2 DESCRIPTION

The System 250N Portable Moisture Analyzer is housed in a conductive polyethylene carrying case to minimize RFI/EMI effects. The cover contains the abbreviated operating instructions, power cord, and manual. The lower section contains the electronics and the heated sample system and moisture probe the System 250N operates on 120 VAC 60 Hz line power.

The unit reads directly in parts-per-million by volume (ppm_v), dew/frost point in degrees Fahrenheit, and pressure in pounds per square inch gage (psig).

1.3 HYGROMETER SPECIFICATIONS

A. ELECTRONIC SPECIFICATIONS

AC Power Supply: 120 VAC, 60 Hz 5 watts with heaters off, 685 watts when heater is on

Accuracy: Better than ± 1.2% above 0°F dew/frost point on ppm_v scale

Better than ± 0.4% above 0°F dew/frost points on dew/frost point scale.
Better than ± 1% on pressure scale

Operating Temperature Range:

32°F to 140°F.

Range: 0.01 to 20,000 ppm_v
-166 to +68°F dew/frost point
0 to 5000 psig

B. MECHANICAL SPECIFICATIONS

Case Dimensions: 15"H x 14"W x 7-1/4"D

Weight: 19 1/2 lbs.

Sample System Construction:

300 series stainless steel - all wetted parts

Max. Recommended Operating Pressure:

5000 psig

C. PROBE SPECIFICATIONS

Type: Panametrics M225

Manufacturer: Panametrics Incorporated
221 Crescent Street
Waltham MA 02254

Input Voltage: 1 volt

Impedance Range: 2 megs to 50K ohms @ 77 Hz (dependent on vapor pressure of water)

Calibration: Each sensor provided with individual calibration

Dew/Frost Point Range:

-80°C to +20°C (-112°F to +68°F)

Accuracy: ± 2°C in range of -65°C to +20°C
± 3°C in range of -80°C to +65°C

Repeatability: ± 0.5°C in range of -65°C to +20°C
± 1.0°C in range of -80°C to -65°C

Operating Temperature:

-110 °C to +70°C (-166°F to +168°F)

Storage Temperature:

Maximum of +70°C

Operating Pressure: 5 microns of Hg to 5000 psig (with M225 probe)

Flow Rate: Gases from Static to 5000 cm/sec linear velocity @ 1 atm.

Response Time: Less than 7 seconds for a 63% step change in moisture content in either wet up or dry down cycle

D. PRESSURE SPECIFICATIONS

1. TRANSDUCER

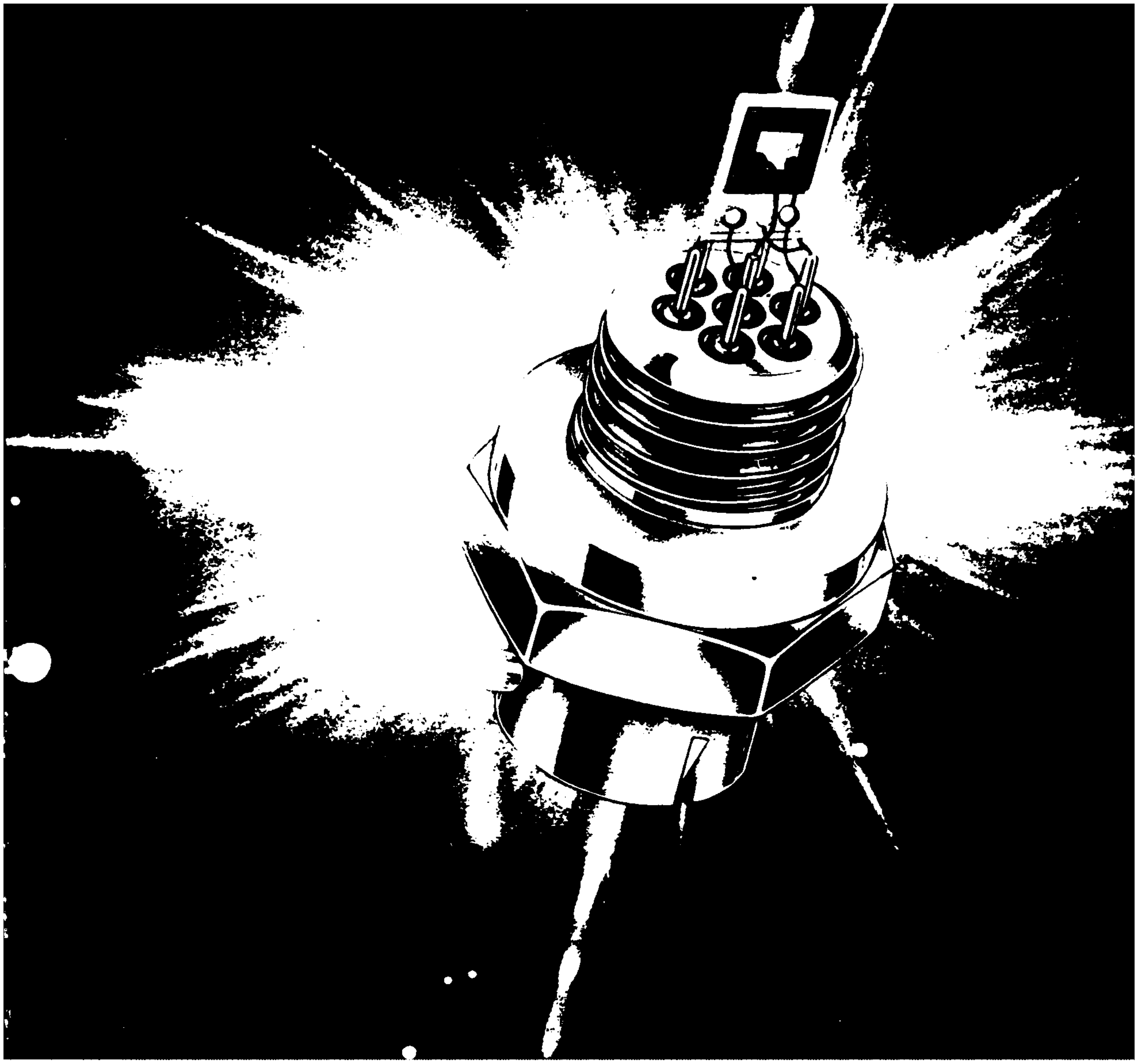
Type: Barksdale Model 300H2-15CG-04-K

Manufacturer: Barksdale Controls Division of
Transamerica Deval
3211 Fruitland Avenue
Los Angeles
CA 90058-0843

Range: 0 to 5000 psig

2. COMBINED ACCURACY

± 5% of reading-- for example,
± 200 psig at 4000 psig



Si-GROMETRIC® Moisture Technology

In the early 'eighties our research and development team achieved the most significant breakthrough ever made in moisture analysis. This took the form of a Si-Grometric moisture sensor constructed from stable, corrosion resistant semi-conductor type materials. Aging prior to use was not required and high temperatures could be withstood without deterioration.

The most remarkable features were the ultra quick response speeds combined with the phenomenal sensitivity to water vapour. The dry down time was less than that for stainless steel sample tubing and dewpoint changes of 0.001 °C could easily be detected.

The Si-Grometer® immediately created considerable international interest and quickly became the experts' first choice in the difficult field of moisture measurement.

Internationally Acclaimed Reliability

The C E G B specified Si-Grometers® for their most stringent and difficult application of reactor boiler leak detection and location systems, and were delighted to discover that after three years' operation all the original sensors were still able to quickly detect an increase of 1ppm, in a background of 300ppm.

Boeing Technical Services in the United States verified the calibration accuracy of a Si-Grometer® at 6 different levels, over the range of −60°C to −20°C frost point, by means of a moisture generator traceable to the American National Bureau of Standards. At each level the instrument greatly exceeded the accuracy claimed, and the Si-Grometer® was identified by their Metrology scientists as the next generation of moisture analysers.

N.P.L. chose a Si-Grometer® to cross reference commercial humidity generators and dryers against the U.K. National Humidity Standard. The 1 minute response speed, even at moisture levels of −80°C Dewpoint (0.5ppm), combined with the high discrimination capability available, provided the requirement of a nulling device which does not significantly contribute to the uncertainties specified on this important calibration exercise.

New Features

Si-Grometers® have been designed to simplify the aquisition of reliable humidity data. They started the era of 'Push Purge'® to verify the presence of water and to reduce the wet sensor dry down time to a few seconds. The leak-tight silicon chip sensor copes with high vacuum to 4000psi and is unaffected by gas flow variations.
A plug-in indicator for the remote sensor option has been developed to give you an additional read-out facility at the sampling point.

Accurate Results in Any Climate

The amount of water on any humidity sensor (in spite of claims made by others) is a function of both the humidity and the sensor temperature. If ignored, this feature causes serious errors. The MCM 'Dewluxe'® option with chip temperature control ensures that all your moisture readings are taken with the sensor temperature level identical to the level maintained on the day the calibration was certified. Measuring with a hot sensor has the added advantage of extending the reliable operating life by minimising contamination problems and eliminating the risk of water condensing on the sensor.

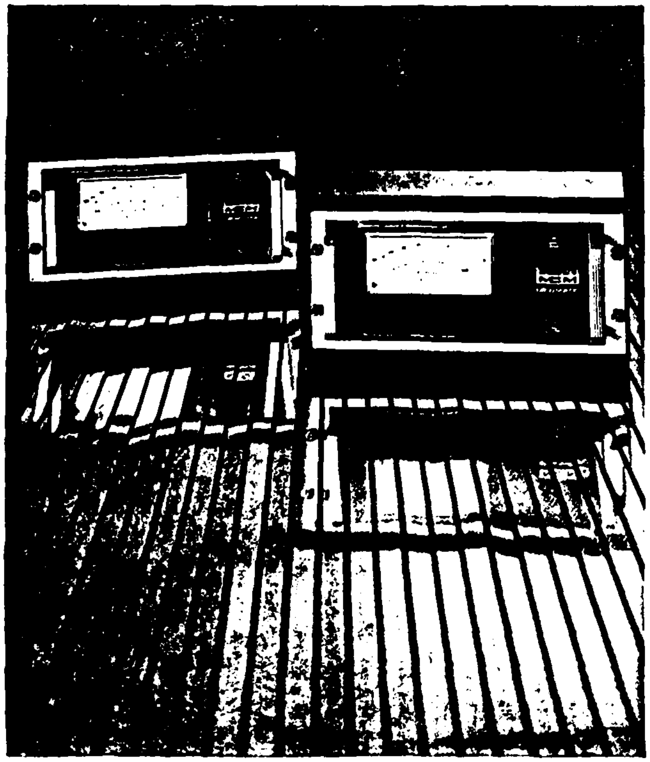
Humidity Range

Si-Grometers® are capable of covering the full humidity range from absolute zero to saturation, with greater discrimination than any conventional system. For hot and humid gases we have produced a sampling line and sensor housing which is suitably heated to prevent condensation. Various standard scales, calibrated in terms of Dewpoint and ppm, are available to suit your area of interest.

Standards

The best moisture analysers require the best standards. A separate brochure describes our unique Moisture Generators which have been verified gravimetrically, under the supervision of the M.O.D. inspectorate. A certificate of registration, number IDL MO1, has been issued to confirm that the AQAP quality assurance requirements have been fulfilled. The products covered by the registration include Moisture Analysers, Moisture Generators, Dryers and Calibrators.

Additional indisputable verification of accuracy has been provided by cross referencing our Moisture Generators to the National Humidity Standard at 15 different humidity levels.



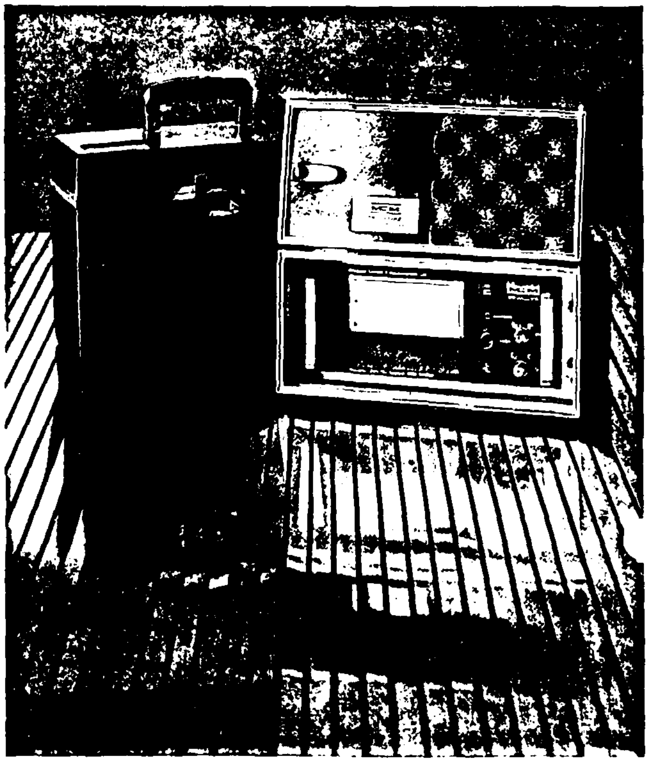


Figure C-14 MCM Hygrometers

PUSH PURGE® Moisture Technology

'Push Purge'® is a unique manually operated stripping mechanism which removes both water and contaminants. The unmistakably advanced technology is an essential feature of modern moisture analysers and it is specified as a requirement on major contracts. Once you have used a 'Si-Grometer'® with 'Push Purge'® you will find that all conventional hygrometers are antiquated and costly to operate.

Spot Checks

Spot check moisture determinations have never been so simple, efficient and accurate.

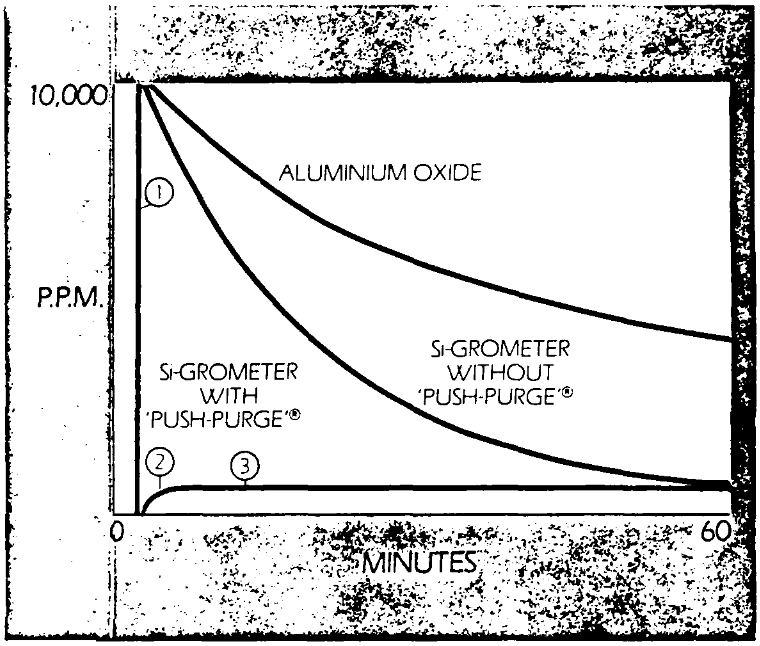
Simple: Spot check operating instructions are:

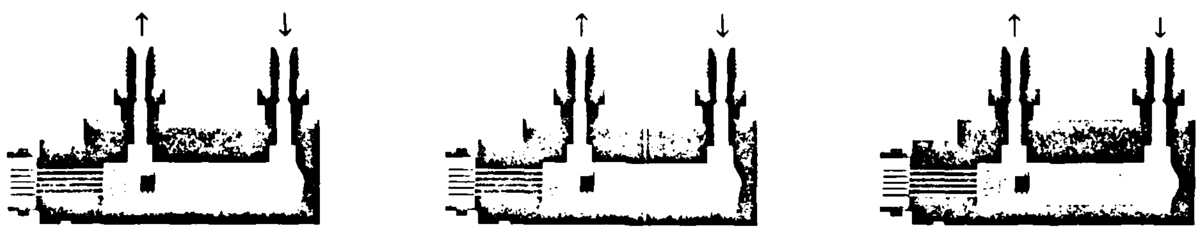
1) Connect the sample gas to the inlet and depress the 'Push Purge' switch for 10 seconds to dry the sensor.

2) Release 'Push Purge', wait 80 seconds and take your reading.

Efficient: Quick result saves operator time, avoids start up delay and reduces the amount of gas required.

Accurate: With 'Push Purge' you always clean the Sensor before measuring, so that the previous reading does not influence the current result.



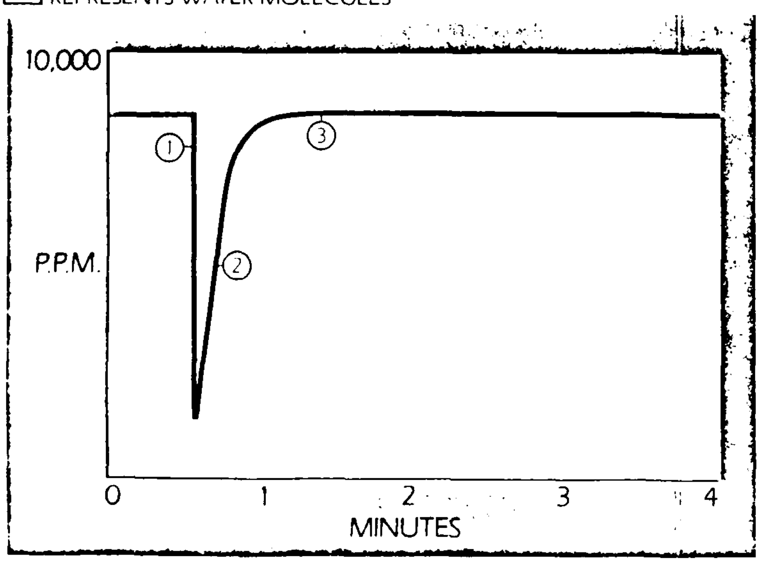


1 DRYDOWN

2 RE-ABSORBS

3 EQUILIBRIUM

☐ REPRESENTS WATER MOLECULES



On-Line Moisture Verification

'Push Purge' will dry a sensor which is surrounded by wet gas to verify a moisture alarm prior to expensive servicing.

1) Ensure that the correct gas flow is purging through the 'Si-Grometer'. Depress the push purge switch for 5 seconds and check that the hygrometer dries down

2) Release 'Push Purge' and the hygrometers should quickly revert to the former wet gas reading, thus confirming correct hygrometer operation

INSTRUMENTATION

All instrumentation used to measure pressure, temperature, and flow was calibrated under the NAVSSES Metrology and Calibration (METCAL) Program IAW NAVSSES Calibration Instruction 4355.2 of 3 September 1974.

Presently, there exists limited capability within the Navy for verifying accuracy of dewpoint indicators. The Navy METCAL program further recommends that indicators found to be inaccurate be returned to the Original Equipment Manufacturer (OEM) for calibration.

All units used during this test were calibrated at the OEM prior to the start of testing.

APPENDIX D

DEWPOINT INDICATOR INFORMATION

TAI

DEW POINT INDICAT(

INDICATOR	COST	SENSOR TECHNOLOGY	THEORY USED FOR CONVERTING DEWPOINTS	PORTABILITY	POWER REQUIREMENTS	OUTPUT SIGNALS	RESPONSE TI
KAHN MD10	$3,000	CAPACITANCE TYPE THIN-FILMED ALUMINUM OXIDE	IDEAL GAS LAWS	PORTABLE	115 VAC OR RECHARGEABLE NiCd BATTERIES	4-20 mA	TYPICAL FOR AL DRY TO WET 1(WET TO DRY
PANAMETRICS 250/250N	$6,000	CAPACITANCE TYPE THIN-FILMED ALUMINUM OXIDE	LDS CURVES	PORTABLE	115 VAC	NONE	TYPICAL FOR AL DRY TO WET 1(WET TO DRY
PANAMETRICS 1000	$3,000 (OBSOLETE)	CAPACITANCE TYPE THIN-FILMED ALUMINUM OXIDE	HYLAND (NBS) METHOD	COULD BE MADE PORTABLE	115 VAC	NONE	TYPICAL FOR AL DRY TO WET 1(WET TO DRY
DUPONT 5700	$20,000	PIEZOELECTRIC CRYSTAL	IDEAL GAS LAWS	NOT PORTABLE	115 VAC	0-5V DC ANALOG	LONG STAF STABILIZATI((1 - 4 H(
MCM DEWLUXE	$6,500	SILICON CHIP	IDEAL GAS LAWS	PORTABLE	115 VAC OR RECHARGEABLE NiCd BATTERIES	4 - 20 mA OR 0 - 10 mV	DRY TO WET 1 WET TO DRY 1
AIR DRY CHILLED MIRROR	$5,000	MANUALLY OPERATED CHILLED MIRROR WITH VORTEX TUBE	NO CONVERSIONS USED	PORTABLE	115 VAC	NONE	15 - 20
GENERAL EASTERN MODEL 1311DR	$11,000	THREE STAGE COOLING OPTICALLY CONTROLLED CHILLED MIRROR	NO CONVERSIONS USED	NOT PORTABLE	115 VAC	0-5V DC ANALOG	N/A
PNEUMETRICS MARK 1	$4,500	CAPACITANCE TYPE THICK-FILMED ALUMINUM OXIDE	IDEAL GAS LAWS	COULD BE MADE PORTABLE	115 VAC	4-20 mA	30 - 60 MINUTE RESPONSE DURING THAN DURING

TABLE 5

DICATOR COMPARISON MATRIX

GNALS	RESPONSE TIME	DIRECT READING	RANGE	PRESSURE RANGE	COMMENTS
A	TYPICAL FOR ALUMINUM OXIDE: DRY TO WET 10 - 15 MINS WET TO DRY 1 - 4 HOURS	DEWPOINT	-148F TO +86F	0 - 5000 PSIG	DEWPOINT CAN BE READ IN F OR C, OTHER READINGS (BASED ON THE IDEAL GAS LAWS) INCLUDE MOISTURE PPMv AND PPMw
	TYPICAL FOR ALUMINUM OXIDE: DRY TO WET 10 - 15 MINS WET TO DRY 1 - 4 HOURS	DEWPOINT	-155F TO +100F	0 - 5000 PSIG	THE DIFFERENCE BETWEEN THE COMMERCIAL 250 UNIT AND THE MILITARY 250N UNIT IS THAT THE 250 READS AT PRESSURE AN DISPLAYS THE PRESSURE DEWPOINT, WHILE THE 250N READS AT PRESSURE AND CONVERTS (BY THE LDS CURVES) TO AN ATMOSPH DEWPOINT
	TYPICAL FOR ALUMINUM OXIDE: DRY TO WET 10 - 15 MINS WET TO DRY 1 - 4 HOURS	IMPEDANCE	-150F TO +75F	0 - 5000 PSIG	THIS UNIT IS NO LONGER COMMERCIALLY MADE, HOWEVER, THE IS IDENTICAL TO THE ONES USED IN THE 250/250N UNITS
NALOG	LONG START-UP STABILIZATION TIMES (1 - 4 HOURS)	PPMv OF MOISTURE	0 - 1000 PPMv	0 - 150 PSIG	NEEDS AUXILLIARY DEHYDRATOR FOR OPERATION, ITS SIZE AN SENSITIVITY RESTRICT ITS USE TO LABORATORY WORK ONLY COST IS PROHIBITIVE
mA OR mV	DRY TO WET 10-30 SECONDS WET TO DRY 10-30 SECONDS	DEWPOINT	RANGES INCLUDE: -58F TO +50F -76F TO +32F -112F TO - 4F	0 - 5000 PSIG	THIS UNIT EMPLOYS THE LATEST IN TECHNOLOGIES, SHOWS SUF RESPONSE TIMES, AND CONTAINS AN OPTIONAL MANUAL PURGING DEVICE TO HELP KEEP THE SENSOR CONTAMINANT-FREE
	15 - 20 MINUTES	DEWPOINT	-150F TO +20F	3000-5000 PSIG	THIS UNIT IS THE STANDARD UNIT CURRENTLY USED BY THE NA HAS AN ACCURACY OF +/- 50F, AND IS CONSIDERED BY MANY C TO BE AN OBSOLETE PIECE OF EQUIPMENT IN THE MOISTURE LE OF 0 - 15 PARTS PER MILLION (NAVY ACCEPTABLE GOOD QUALI
ALOG	N/A	DEWPOINT	-85F TO +95F	0 - 300 PSIG	UNIT WOULD NOT FUNCTION BELOW -40F, COMPONENTS CONTINUA AND FUSES REPEATEDLY BLEW OUT, UNIT WAS USED FOR VERY S OF TIME DUE TO INABILITY TO PERFORM IN THE LOWER MOIST AS SPECIFIED BY THE MANUFACTURER
	30 - 60 MINUTES, FASTER RESPONSE DURING WET TO DRY THAN DURING DR TO WET	DEWPOINT	-80F TO +20F	0 - 5000 PSIG	THIS UNIT WAS THE FORE-RUNNER TO THE THIN-FILMED ALUMI SENSORS, AND HAS SINCE BEEN OUT-DATED. UNIT SHOWED UN RESPONSE IN GOING FROM WET TO DRY AND DRY TO WET, BEIN OF WHAT IS TYPICAL FOR ALUMINUM OXIDE SENSORS

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ATRIX

URE RANGE	COMMENTS
000 PSIG	DEWPOINT CAN BE READ IN F OR C, OTHER READINGS (BASED ON THE IDEAL GAS LAWS) INCLUDE MOISTURE PPMv AND PPMw
5000 PSIG	THE DIFFERENCE BETWEEN THE COMMERCIAL 250 UNIT AND THE MILITARY 250N UNIT IS THAT THE 250 READS AT PRESSURE AND DISPLAYS THE PRESSURE DEWPOINT, WHILE THE 250N READS AT PRESSURE AND CONVERTS (BY THE LDS CURVES) TO AN ATMOSPHERIC DEWPOINT
000 PSIG	THIS UNIT IS NO LONGER COMMERCIALLY MADE, HOWEVER, THE SENSOR IS IDENTICAL TO THE ONES USED IN THE 250/250N UNITS
150 PSIG	*NEEDS AUXILLIARY DEHYDRATOR* FOR OPERATION, ITS SIZE AND SENSITIVITY RESTRICT ITS USE TO LABORATORY WORK ONLY COST IS PROHIBITIVE
000 PSIG	THIS UNIT EMPLOYS THE LATEST IN TECHNOLOGIES, SHOWS SUPERIOR RESPONSE TIMES, AND CONTAINS AN OPTIONAL MANUAL PURGING DEVICE TO HELP KEEP THE SENSOR CONTAMINANT-FREE
000 PSIG	THIS UNIT IS THE STANDARD UNIT CURRENTLY USED BY THE NAVY HAS AN ACCURACY OF +/- 50F, AND IS CONSIDERED BY MANY OPERATORS TO BE AN OBSOLETE PIECE OF EQUIPMENT IN THE MOISTURE LEVELS OF 0 - 15 PARTS PER MILLION (NAVY ACCEPTABLE GOOD QUALITY AIR)
300 PSIG	UNIT WOULD NOT FUNCTION BELOW -40F, COMPONENTS CONTINUALLY FROZE AND FUSES REPEATEDLY BLEW OUT, UNIT WAS USED FOR VERY SHORT PERIOD OF TIME DUE TO INABILITY TO PERFORM IN THE LOWER MOISTURE RANGE AS SPECIFIED BY THE MANUFACTURER
00 PSIG	THIS UNIT WAS THE FORE-RUNNER TO THE THIN-FILMED ALUMINUM OXIDE SENSORS, AND HAS SINCE BEEN OUT-DATED. UNIT SHOWED UNCHARACTERISTIC RESPONSE IN GOING FROM WET TO DRY AND DRY TO WET, BEING THE OPPOSITE OF WHAT IS TYPICAL FOR ALUMINUM OXIDE SENSORS

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TABLE 6: DUPONT 5700 CONVERSIONS

This scale is used to convert PPMv of moisture at atmospheric pressure as read off the DuPont 5700 into a corresponding dewpoint at 4000 psig. This scale was generated by a computer program based on the National Bureau of Standards (NBS) equations.

PPMv	Dewpoint (F)	PPMv	Dewpoint (F)
0.05	-99	4	-27
0.1	-89	4.2	-25
0.15	-83	4.4	-25
0.2	-79	4.6	-24
0.25	-75	4.8	-23
0.3	-72	5	-22
0.35	-70	5.5	-20
0.4	-68	6	-18
0.45	-66	7	-15
0.5	-64	8	-12
0.6	-61	9	-10
0.7	-58	10	-8
0.8	-56	15	1
0.9	-54	20	7
1	-52	25	12
1.1	-51	30	16
1.2	-49	35	20
1.3	-48	40	23
1.4	-46	45	25
1.5	-45	50	28
1.6	-44	55	30
1.7	-43	60	33
1.8	-42	65	34
1.9	-41	70	36
2	-40	75	37
2.2	-38	80	39
2.4	-36	85	40
2.6	-35	90	42
2.8	-33	95	43
3	-32	100	44
3.2	-31	105	45
3.4	-30	110	47
3.6	-29	115	48
3.8	-28	120	49
		125	50
		130	51

TABLE 7: PANAMETRICS 1000 CONVERSIONS

This scale (provided by Panametrics) is used to convert the MH value read off the Panametrics 1000 unit into a dewpoint at applied pressure (4000 psig).

MH value	Dewpoint (F)
0.3583	-110
0.3648	-100
0.3724	-90
0.3817	-80
0.3868	-75
0.3933	-70
0.3998	-65
0.4064	-60
0.4140	-55
0.4222	-50
0.4305	-45
0.4387	-40
0.4524	-35
0.4661	-30
0.4799	-25
0.4936	-20
0.5122	-15
0.5309	-10
0.5495	-5
0.5731	0
0.5967	5
0.6202	10
0.6438	15
0.6800	20
0.7141	25
0.7482	30
0.8041	35
0.8746	40
0.9450	45
1.0155	50
1.1128	55
1.2101	60
1.3074	65
1.3658	68

TABLE 8: MCM DEWLUXE CONVERSIONS

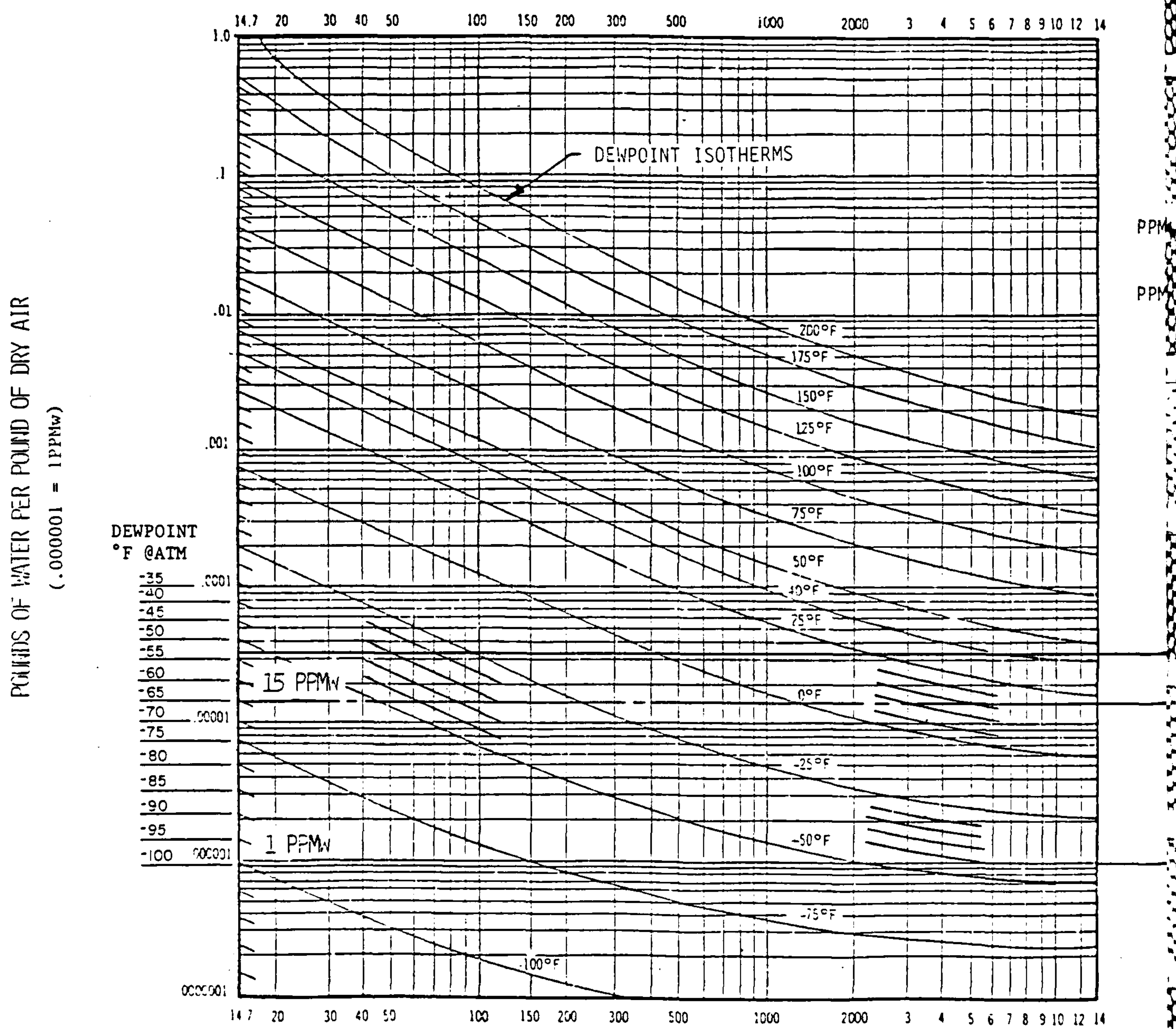
This scale is used to convert the dewpoint read off the MCM Dewluxe indicator (at 120 psig) to a corresponding dewpoint at 4000 psig.

Dewpoint (F) read at 120 psig	Corresponding dewpoint at 4000 psig
-8	65
-12	60
-16	55
-18	50
-21	45
-24	40
-27	35
-33	30
-35	25
-37	20
-42	15
-46	10
-48	5
-51	0
-55	-5
-58	-10
-61	-15
-63	-20
-68	-30
-72	-40
-75	-50
-78	-60
-82	-70

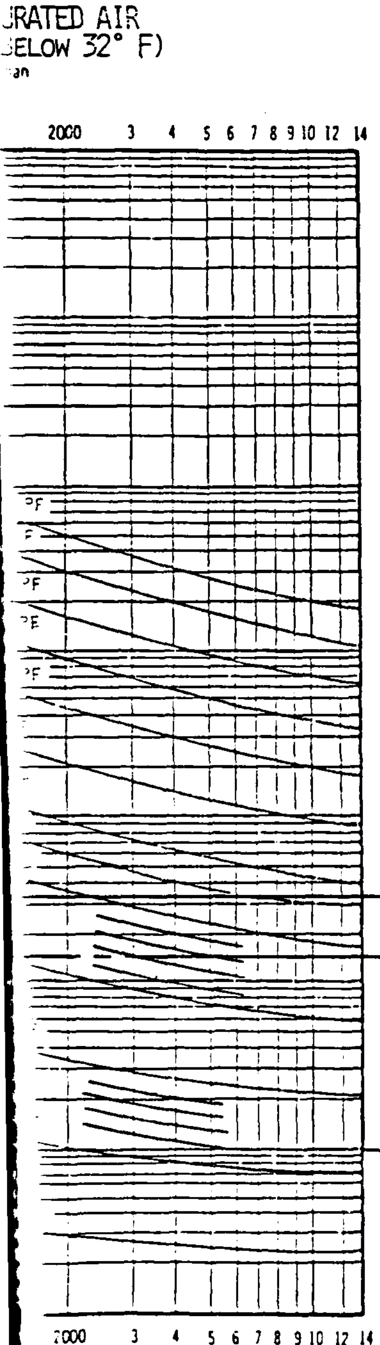
GRAPH N

LDS CHART FOR WATER CONTENT OF SATURATED AIR
(BASED ON VAPOR PRESSURE OVER ICE BELOW 32° F)

Ref. E.M. Landsbaum, W.S. Dodds and L.F. Stutzman
Northwestern University - 1955



PRESSURE (PSIA)
PSIA = PSIG+ 14.7



TEMP CONVERSIONS

$^{o}F = 9/5^{o}C + 32$
$^{o}C = 5/9\ (^{o}F-32)$

PPM CONVERSIONS

$$PPMv = PPMw \times \frac{28.96 \text{ MOL. WT. AIR}}{18.02 \text{ MOL. WT. } H_2O}$$

$$PPMw = PPMv \times \frac{18.02 \text{ MOL. WT. } H_2O}{28.96 \text{ MOL. WT. AIR}}$$

NOTES

1) TO ENSURE MOISTURE DOES NOT CONDENSE IN THE AIR BANKS A DEWPOINT BETTER THAN OR EQUAL TO -60°F AT ATMOSPHERIC PRESSURE (EQUIVALENT TO +23°F @4500 PSIG) IS REQUIRED. THIS IS BASED ON +28°F AS THE LOWEST TEMPERATURE BEFORE FREEZING OF SEAWATER.

2) NAVY ACCEPTABLE MOISTURE LEVELS ARE FOUND IN NSTM:

   NAVSEA 0949-LP-056-8010
   NAVSEA 0901-LP-490-0003
   CHAPTER 9490 CHANGE 10 OF 4/15/84

3) DEWPOINT - THE TEMPERATURE TO WHICH AIR MUST BE COOLED FOR DEW TO FORM.

4) ISOTHERM - A CURVE ON WHICH EVERY POINT REPRESENTS THE SAME TEMPERATURE.

5) CURVES COPIED FROM NSTM: NAVSEA 0949-LP-056-8010

BREAKTHROUGH FOR TESTING.

UPPER LIMIT FOR NAVY, GOOD QUALITY AIR PRODUCED BY HEAT REACTIVATED DESICCANT DEHYDRATORS.

AT 15 PPMw:

-65°F @ATM ≃ -40°F @ 80 PSIG(95 PSIA)
≃ +12°F @ 3000 PSIG(3015 PSIA)
≃ +15°F @ 4500 PSIG(4515 PSIA)

AT 1 PPMw:

-100°F @ ATM ≃ -80°F @ 80 PSIG(95 PSIA)
≃ -47°F @ 3000 PSIG ≃ -45°F @ 4500PSIG(4515 PSIA)

CHART PREPARED BY NAVSSES CODE 024B (215) 897-7249, JUNE 1988.

2

APPENDIX E

SAMPLE HPAD/HPAC DATA SHEETS

HPAD DATA SHEET

DATE ______________________

DAY ______________________

OPERATOR ______________________

HOURS ON LINE ______________________

TIME																														
HPAD INLET PRESS, PSIG																														
HP AIR FLOW, CFH																														
HP AIR TEMP, °F																														
PURGE AIR PRESS, PSIG																														
PURGE AIR TEMP, °F																														
PURGE AIR DEW PT, °F																														
DEHYD L CHAMBER DRYING																														
DEHYD R CHAMBER DRYING																														
DEHYD L CHAMBER REACT																														
DEHYD R CHAMBER REACT																														
HP AIR DEW PT																														

REMARKS ______________________

HPAC DATA SHEET

DATE ____________

DAY ____________

OPERATOR ____________________

	SHUT-ON	MIN	NORMAL	MAX																						
FRAME OIL PRESSURE (PSIG)	15 a	15	25-30	50																						
PRESSURE 1st STAGE	60 b	32	40-45*	59																						
(PSIG) 2nd STAGE	330 b	209	250-270*	324																						
3rd STAGE	1225 b	940	1055-1075*	1200																						
4th STAGE g	6200 b 4900 a	4200c	4200*-4675*	5100																						
TEMP 1st STAGE-suct		49	84	122																						
(°F) 1st STAGE-disch	430 a		336	415																						
2nd STAGE-suct			122																							
2nd STAGE-disch	430 a		374	415																						
3rd STAGE-suct			119																							
3rd STAGE-disch	430 a		356	415																						
4th STAGE-suct			119																							
4th STAGE-disch	430 a		376	415																						
FINAL DISCH TEMP		115		125																						
CLG WTR OUTLET TEMP	125 a	95	95-115*	120																						
CRANKCASE OIL TEMP		135		170*																						
CRANKCASE OIL LVL		LOW	MIDDLE	HIGH																						
CYL LUBE OIL LVL		1/2		FULL																						
CLG WTR PMP DISCH PRESS		25		175																						
CLG WTR INLET TEMP				95																						
LUB FLOW RATE 1st STAGE		10d	11	15e																						
(DROPS/MIN) 2nd STAGE		10d	11	15e																						
3rd STAGE		10d	13	15e																						
4th STAGE		10d	13	15e																						
CUNO AIR FILTER	DRAIN BOTH EVERY HR.																									
MOISTURE SEP FLASK	DRAIN BOTH EVERY HR.																									
DHYR PREFILTER	DRAIN EVERY TOWER CHGE-OVER																									
CONDENSATE DRAINAGE	MUST BE OBSERV.-8 MIN CYCLE																									

* CIRCLE LOG VALUES WHICH ARE OUTSIDE THE NORMAL RANGE LIMITS INDICATED IN RED.

a - WILL SHUT DOWN AUTOMATICALLY.

b - RELIEF VALVE LIFTS.

c - WILL CAUSE WET AIR TO BE SUPPLIED TO BANKS, RESET BACK PRESSURE CONTROL VALVE ON DEHYDRATOR.

d - INADEQUATE LUBRICATION BELOW THIS RATE.

e - CAUSES EXCESS CARBON & OIL CARRYOVER ABOVE THIS RATE.

f - REPLACE ELEMENT EVERY 200 HRS. COMPRESSOR USE OR MONTHLY, WHICHEVER FIRST.

g - DISCHARGE PRESSURES BETWEEN 4675 PSIG AND RELIEF VALVE SETTING MAY BE DUE TO DESICCANT PLUGGING OF FILTERS.

APPENDIX F

NOTES ON MAINTENANCE DURING TESTING

COMPRESSOR MAINTENANCE

In the early stages of Phase I testing, problems with air leaks at tube fittings as well as second and third stage valves were prominent.

During Phase II more air leaks were encountered around the three cylinder head gaskets. In addition, low fourth stage pressures were discovered to be the result of broken fourth stage rings.

During Phase III, the compressor ran well with only normal operating maintenance being performed.

While operating in Phase IV, the compressor's stage pressures dropped substantially. Carbon build-up on the valves was found to be the cause of this problem. All valves as well as third and fourth stage cylinder heads were pulled and cleaned. At this point, the compressor had clocked over 500 hours of operation. This cleaning is considered typical maintenance for lubricated compressors.

Towards the middle of Phase V, another cleaning of valves and heads was required (after approximately 1200 total hours of operation).

On a whole, the compressor ran well, requiring only normal maintenance during testing.

DEHYDRATOR MAINTENANCE

NOTE: The dehydrator used for testing was new from the manufacturer.

After approximately 200 hours of operation, the dehydrator showed problems typical of this unit. Leaks developed in, on and around the P1200 manifold, the bottom screw plugs for both desiccant towers, the purge line for the left tower, and various upper manifold control valves. These problems continued throughout all phases of testing. Leaks varied in size, depending on location. Most leaks were due to worn/failed o-rings.

On a whole, the dehydrator had many failures for a new unit, and this is reflected by the high maintenance costs seen in the Fleet.

APPENDIX G

PROCEDURE FOR OIL EXTRACTION

PROCEDURE FOR OIL EXTRACTION

At the end of each Phase, various system elements and flush samples were removed and sent to the Chemistry Lab for oil content analysis. CUNO filter housings were washed with Freon 113, and the wash fluid was collected. CUNO filter elements, prefilter elements and desiccant from the towers were removed and placed in containers.

The Freon washing samples were filtered to remove particulate matter and were then slowly evaporated on a hot plate until the volumes were significantly reduced. The samples were then transferred to a previously weighed evaporating dish and heated until only an oily residue remained. The dish and oil were then reweighed, and the grams of oil in the sample obtained by difference.

The filter and desiccant samples were first extracted by soaking in a specified volume of Freon 113, and then the grams of oil were obtained by the procedure outlined above.

In general, the CUNO filter extractions contained the greatest amount of oil residue.

APPENDIX H

PHASES I - V OPERATING HOURS

TABLE 9: PHASE I OPERATING HOURS

DATE	LEFT TOWER	RIGHT TOWER	COMMENTS
4/8/87	3.5	4	RUNNING ONE COMPLETE CYCLE PER DAY
4/9/87	4	3.5	
4/10/87		3.5	
4/13/87	7		DECISION TO RUN ON ONE TOWER UNTIL BREAKTHROUGH
4/14/87	1		
4/16/87	5.5		
4/17/87	7.5		
4/20/87	7.5		
4/21/87	7.5		
4/22/87	4		
4/23/87	5		
4/24/87	7.75		
4/27/87		7.75	NO BREAKTHROUGH, SWITCHED TOWERS AFTER TWO COMPLETE REACTIVATIONS
4/28/87		7.75	THOUGHT BREAKTHROUGH WOULD OCCUR IN ABOUT 12 HOURS
4/29/87		7.75	
4/30/87		7.5	
5/4/87		4	
5/5/87		7.75	
5/6/87		7.75	
5/7/87		6	
5/8/87		2	
5/11/87		3	
5/12/87		9	
5/13/87		7.5	
5/14/87		7.5	BREAKTHROUGH OCCURED AFTER 85.75 HOURS OF OPERATION, END OF PHASE I
PHASE I SUBTOTALS	60.25	96.25	
PHASE I TOTAL	156.5		
TEST TOTAL	156.5		

Testing began on 8 April 1987. New CUNO filters and new desiccant were installed prior to start of test. For the first two days, the dehydrator was run on four hour cycles (one four hour drying and one four hour reactivation period per tower per day). On 13 April, the decision was made to run on one tower until tower breakthrough occured. The criterion for breakthrough was established as a dewpoint temperature of -20°F at system pressure according to the Pneumetrics monitoring unit. On 27 April, no breakthrough had occured (after 53.25 hours of operation on the left tower). The decision was made to switch to the right tower. This was done for two reasons: 1) breakthrough time had been estimated to be only 12 to 18 hours per tower and 2) uncertain as to whether dewpoint indicators were tracking properly. On 14 May, breakthrough on the right tower occured after 85.75 hours. The system was shut down, CUNO filter IIA removed, CUNO II and III housings flushed with Freon 113 to remove accumulated oil, desiccant removed, and the prefilter removed. The above samples were sent to the lab for oil analysis. See Appendix B for oil analysis results. Total Phase I's operating time: 156.5 hours.

NOTE: Due to lack of oil accumulation in CUNO III, the decision was made to discontinue use and the valve into CUNO III was shut.

Total compressor consumption of lubricating oil during Phase I: 13.5 quarts

TABLE 10: PHASE II OPERATING HOURS

DATE	LEFT TOWER	RIGHT TOWER	COMMENTS
6/1/87		5	
6/2/87	3.75	3.75	
6/3/87		6.5	
6/4/87		5	
6/5/87		7	
6/6/87		6.75	
6/7/87		6.75	
6/8/87		6.5	
6/9/87		7	
6/10/87		6.75	
6/11/87		6.75	
6/12/87		6.75	BREAKTHROUGH OCCURED AFTER 74.5 HOURS, END OF PHASE II
PHASE II SUBTOTALS	3.75	74.5	
PHASE II TOTAL	78.25		
TEST TOTAL	234.75		

Testing began on 1 June 1987, with dehydrator set on the right tower. After 74.5 hours, the right tower reached breakthrough. The system was shut down, CUNO IIB filter removed, and CUNO II housing flushed with Freon 113 to remove oil. The above samples were sent to the lab for oil analysis. See Appendix B for oil analysis results. Total Phase II's operating time: 78.25 hours.

Total compressor consumption of lubricating oil during Phase II: 4 quarts

TABLE 11: PHASE III OPERATING HOURS

DATE	LEFT TOWER	RIGHT TOWER	BYPASS	COMMENTS
6/15/87			4.5	TESTING BYPASS CARTRIDGE FOR PNSY
6/16/87			6.5	
6/17/87			4.75	
6/18/87		6		
6/19/87		3		
6/22/87		6		
6/23/87	7			
6/24/87	7			
6/25/87	7			
6/26/87	6			
6/29/87	6.75			
6/30/87	6.5			
7/1/87	7.25			
7/2/87	7.25			
7/6/87	6.75			
7/7/87	3	3.75		BREAKTHROUGH OCCURED AFTER 64.5 HOURS, REACTIVATED LEFT TOWER
7/8/87	2.25			
7/9/87	6.5			
7/10/87	7.25			
7/13/87	6.5			
7/14/87	6.75			
7/15/87	7.25			
7/16/87	6.75			
7/17/87	3.75			BREAKTHROUGH OCCURED AFTER 47 HOURS, END OF PHASE III
PHASE III SUBTOTALS	111.5	18.75	15.75	
PHASE III TOTAL	146			
TEST TOTAL	380.75			

Testing began on 15 June 1987, with the dehydrator set on the left tower. After 64.5 hours, left tower reached breakthrough. The left tower was reactivated and placed back on line, and reached breakthrough again after 47 hours. The system was shut down, CUNO IA and CUNO IIC filters removed, CUNO I and CUNO II housings flushed with Freon 113 to remove oil, and desiccant removed. The above samples were taken to the lab for oil analysis. See Appendix B for oil analysis results. Total Phase III's operating time: 146 hours.

Total compressor consumption of lubricating oil during Phase III: 16.5 quarts

TABLE 12: PHASE IV OPERATING HOURS

DATE	LEFT TOWER	RIGHT TOWER	COMMENTS
7/18/87	24		BEGAN CONTINUOUS TESTING
7/19/87	24		
7/20/87	19	5	BREAKTHROUGH OCCURED AFTER 53 HOURS, REACTIVATED LEFT TOWER
7/21/87	24		
7/22/87	19.75	4.25	BREAKTHROUGH OCCURED AFTER 47.25 HOURS, REACTIVATED LEFT TOWER
7/23/87	24		
7/24/87	19.5	4.5	BREAKTHROUGH OCCURED AFTER 47.5 HOURS, REACTIVATED LEFT TOWER
7/25/87	24		
7/26/87	18	6	BREAKTHROUGH OCCURED AFTER 48.5 HOURS, REACTIVATED LEFT TOWER
7/27/87	20.5	3.5	
7/28/87	24		
7/29/87	19.5	4.5	BREAKTHROUGH OCCURED AFTER 48 HOURS, REACTIVATED BOTH TOWERS
7/30/87	24		
7/31/87	19.75	4.25	BREAKTHROUGH OCCURED AFTER 48 HOURS, REACTIVATED LEFT TOWER
8/1/87	24		
8/2/87	19.5	4.5	BREAKTHROUGH OCCURED AFTER 45 HOURS, REACTIVATED LEFT TOWER
8/3/87	24		
8/4/87	19.5	4.5	BREAKTHROUGH OCCURED AFTER 43.5 HOURS, REACTIVATED LEFT TOWER
8/5/87	24		
8/6/87	19.75	4.25	BREAKTHROUGH OCCURED AFTER 41 HOURS, REACTIVATED LEFT TOWER
8/7/87	24		
8/8/87	19.75	4.25	BREAKTHROUGH OCCURED AFTER 41.25 HOURS, REACTIVATED LEFT TOWER
8/9/87	24		
8/10/87	19.75	4.25	BREAKTHROUGH OCCURED AFTER 39.75 HOURS, REACTIVATED LEFT TOWER
8/11/87	22	0.5	BREAKTHROUGH OCCURED AFTER 41.5 HOURS, REACTIVATED LEFT TOWER
8/12/87	20.25	3.75	
8/13/87	22.5		BREAKTHROUGH OCCURED AFTER 42.75 HOURS, END OF PHASE IV
PHASE IV SUBTOTALS	587	58	
PHASE IV TOTAL	645		
TEST TOTAL	1025.75		

Testing began on 18 July 1987. The decision was made to run the test continuously (24 hours a day, 7 days a week) and on bypass around CUNO II filter for approximately 3 to 4 weeks. This was done for the following reasons: 1) to compare capabilities of various dewpoint indicators 2) to document the decline in breakthrough time 3) to test CUNO filter absorbtion and 4) to excercise the test site machinery in continuous operation. The system was shut down on 13 August 1987, CUNO filter IB removed, CUNO I housing flushed with Freon to remove oil, prefilter removed and desiccant removed. The above samples were sent to the lab for oil analysis. See Appendix B for oil analysis results. Total Phase IV's operating time: 645 hours.

Total compressor consumption of lubricating oil during Phase IV: 63 quarts

TABLE 13: PHASE V OPERATING HOURS

DATE	LEFT TOWER	RIGHT TOWER	COMMENTS
8/25/87	5.5	4	NO LONGER RUNNING CONTINUOUSLY, REACTIVATED LEFT TOWER AT 400F
8/26/87	10.75		
8/27/87	11		
8/28/87	11		
8/31/87	10.75		REACTIVATED RIGHT TOWER AT 400F
9/1/87	11.25		REACTIVATED RIGHT TOWER AT 400F
9/2/87	11.25		BREAKTHROUGH OCCURED AFTER 61 HOURS
9/3/87	5.5	4	REACTIVATED LEFT TOWER AT 400F
9/4/87	11		
9/8/87	11.25		
9/9/87	11.25		
9/10/87	11		
9/11/87	7.25	4	BREAKTHROUGH OCCURED AFTER 52.5 HOURS, REACTIVATED LEFT TOWER AT 300F
9/14/87	6.75		
9/15/87	7.25		
9/16/87	7.5		
9/17/87	7.5		
9/18/87	7.5		
9/21/87	6.75		
9/22/87	7.5		BREAKTHROUGH OCCURED AFTER 46 HOURS
9/23/87	7.25		
9/24/87	1.25	4	REACTIVATED LEFT TOWER AT 300F
9/25/87	7		
9/28/87	7.25		
9/29/87	7.5		
9/30/87	7.5		
10/1/87	7.5		
10/2/87	7.5		
10/5/87	7		BREAKTHROUGH OCCURED AFTER 51.5 HOURS
10/6/87	5.25		
10/7/87	5		
10/8/87	3.25	4	REACTIVATED LEFT TOWER AT 300F
10/9/87	7.5		
10/13/87	7.5		
10/14/87	7.25		
10/15/87	7.5		
10/16/87	7.25		
10/19/87	7		
10/20/87	7.25		BREAKTHROUGH OCCURED AFTER 50.5 HOURS
10/21/87	7		
10/22/87	3.25	4	REACTIVATED LEFT TOWER AT 200F
10/23/87	7.25		
10/26/87	7.25		
10/27/87	7.25		
10/28/87	7.25		
10/29/87	7.25		BREAKTHROUGH OCCURED AFTER 39.5 HOURS
10/30/87	7.5		
11/2/87	3	4.25	REACTIVATED LEFT TOWER AT 200F
11/3/87	7.5		
11/4/87	6.25		
11/5/87	7.25		

TABLE 13: PHASE V OPERATING HOURS (CONTINUED)

DATE	LEFT TOWER	RIGHT TOWER	COMMENTS
11/6/87	7.5		
11/9/87	7.25		BREAKTHROUGH OCCURED AFTER 33.25 HOURS
11/10/87	7.5		
11/12/87	3.25	4	REACTIVATED LEFT TOWER AT 200F
11/13/87	7.5		
11/16/87	4.5		
11/17/87	6.75		
11/18/87	7		
11/19/87	7.5		BREAKTHROUGH OCCURED AFTER 27.75 HOURS
11/20/87	7.25		
11/23/87	7.25		
11/24/87	3	4	REACTIVATED LEFT TOWER WITH NO HEAT
11/25/87	7.25		BARELY ANY AIR QUALITY IMPROVEMENT NOTICED
11/27/87	2.75	4	REACTIVATED WITH NO HEAT, BARELY ANY AIR QUALITY IMPROVEMENT
11/30/87	3.25	4	REACTIVATED LEFT TOWER AT 100F
12/1/87	7.25		
12/2/87	7.25		BREAKTHROUGH OCCURED AFTER 10.75 HOURS
12/3/87	3.25	4	REACTIVATED LEFT TOWER AT 100F
12/4/87	7.5		
12/7/87	7		BREAKTHROUGH OCCURED AFTER 9.25 HOURS
12/8/87	0.5		
12/10/87	2.25	4	REACTIVATED LEFT TOWER AT 400F
12/11/87	7		
12/14/87	1		
12/16/87	7		
12/17/87	7.25		
12/18/87	7.25		
12/21/87	7.5		
12/22/87	7.25		BREAKTHROUGH OCCURED AFTER 43.75 HOURS
12/23/87	3.5		
12/28/87	2.5	4	REACTIVATED LEFT TOWER AT 400F
12/29/87	3.5	4	REACTIVATED LEFT TOWER AT 400F
12/30/87	7		
12/31/87	7		
1/4/88	7.25		END OF PHASE V
PHASE V SUBTOTALS	581.5	60.25	
PHASE V TOTAL	641.75		
TEST TOTAL	1667.5		

Testing began on 25 August 1987, with the dehydrator set on the left tower. For Phase V, reactivation temperatures were gradually reduced to observe the effects on breakthrough times. Due to erratic performance of the Pneumetrics dewpoint monitor, the criterion for breakthrough was re-established as +35°F dewpoint at system pressure according to the *Panametrics 1000 dewpoint monitor*. This value was chosen as the best to retain consistent breakthrough standards. The system was shut down on 4 January 1988, CUNO filter IC removed, CUNO I housing flushed with Freon to remove oil, prefilter removed, and desiccant removed. The above samples were sent to the lab for oil analysis. See Appendix B for oil analysis results. Total Phase V's operating time: 641.75 hours.

Total compressor consumption of lubricating oil during Phase V: 95 quarts